American Medical Association
Physicians dedicated to the health of America

The Illustrated Guide to Functional Anatomy of the Musculoskeletal System

Rene Cailliet

American Medical Association
Physicians dedicated to the health of America

The Illustrated Guide to

Functional Anatomy

of the

Musculoskeletal System

AMA press

Rene Cailliet, MD

AMA Press

Vice President, Business Products: Anthony J. Frankos
Publisher: Michael Desposito
Director, Production and Manufacturing: Jean Roberts
Senior Acquisitions Editor: Barry Bowlus
Developmental Editor: Katharine Dvorak
Copy Editor: Kathleen Louden
Director, Marketing: J. D. Kinney
Marketing Manager: Reg Schmidt
Senior Production Coordinator: Rosalyn Carlton
Senior Print Coordinator: Ronnie Summers

Printed in the United States of America.

Internet address: www.ama-assn.org

Additional copies of this book may be ordered by calling 800 621-8335. Mention product number OP857003.

ISBN 1-57947-408-X

Library of Congress Cataloging-in-Publication Data

Cailliet, Rene.
The illustrated guide to functional anatomy of the musculoskeletal system / Rene Cailliet.
p. ; cm.
Includes bibliographical references and index.
ISBN 1-57947-408-X
1. Musculoskeletal system—Anatomy. 2. Musculoskeletal system—Anatomy—Atlases.
[DNLM: 1. Musculoskeletal System—anatomy & histology. 2. Musculoskeletal Diseases—Atlases. 3. Musculoskeletal System—anatomy & histology—Atlases. WE 101 C134i 2004] I. Title.

QM100.C355 2004
611'.7—dc21
2003007331

The authors, editors, and publisher of this work have checked with sources believed to be reliable in their efforts to confirm the accuracy and completeness of the information presented herein and that the information is in accordance with the standard practices accepted at the time of publication. However, neither the authors, editors, and publisher, nor any party involved in the creation and publication of this work warrant that the information is in every respect accurate and complete, and they are not responsible for any errors or omissions or for any consequences from application of the information in this book.

In light of ongoing research and changes in clinical experience and in governmental regulations, readers are encouraged to confirm the information contained herein with additional sources, in particular as it pertains to drug dosage and usage. Readers are urged to check the package insert for each drug they plan to administer for any change in indications and dosage and for additional warnings and precautions, especially for new or infrequently used drugs.

A Japanese version of this book has been published by Ishiyaku Publishers, Inc, Tokyo, under the title *Functional Anatomy of the Musculoskeletal System: Illustrated*. Copyright © 2002.

BQ75:03-P-076:08/03

CONTENTS

ABOUT THE AUTHOR

Rene Cailliet, MD, is Professor Emeritus at the University of Southern California School of Medicine and a clinical professor at the department of Physical Medicine Rehabilitation at the UCLA School of Medicine. He has written eleven texts on musculoskeletal problems, which have been published in nine languages and sold more than 1.2 million copies.

INTRODUCTION

There is little debate in the history of medicine that modern medical methods had their origin in France in the early 1800s.[1] Medicine emulated methods gained by physiochemical sciences gained in the 17th and 18th centuries. Foucault,[2] in *The Birth of the Clinic,* stated that "modern medical truth is defined in terms of objectivity ... defined in terms of visibility." He pointed out that medicine had failed to incorporate the pathological anatomy of Morgagni, who stated that the organ was the site of pathology. The organ and how it functions is the basis of medical understanding. Nowhere is this more apparent than in the functional anatomy of the musculoskeletal system.

Kurt Kroenke,[3] in performing epidemiologic studies, commented that "common symptoms are usually *not* associated with a tissue diagnosis." This does not apply to the neuromusculoskeletal system.

For years, the basis for neuromuscular dysfunction with resultant pain has alluded to impaired function, but a meaningful analysis of impaired neuromusculoskeletal "function" based on functional anatomy has not been stressed. In today's medical society, *functional* anatomy has not been adequately addressed, and merely gross anatomy is presented to future physicians and practitioners.

In the foreword of *Clinical Biomechanics of the Spine*, Alf Nachemson states, "The sad truth is that this outstanding amount of increased knowledge has not been mirrored at all in any scientific evidence of improved care for our patients with spinal disorders."[4] This can be stated about functional anatomy, as being the basis of biomechanics in all extremities as well as the spine.

Michelangelo in his excellent paintings in the Sistine Chapel in Rome, Italy, demonstrated outstanding knowledge of anatomy but without expressing its function. The newer methods of imaging, such as computed tomography (CT) and magnetic resonance imaging (MRI), clearly depict the soft tissues of the body that were not visible on routine radiologic studies, but they also do not explain or demonstrate function.

By understanding and clinically evaluating normal functional anatomy and ascertaining how deviation from normal function causes impairment, practitioners can elicit a meaningful diagnostic study and an appropriate therapeutic approach.

REFERENCES

1. Sullivan M. The problem of pain in the clinicopathological method. *Clin J Pain.* 1998;14:197-201.
2. Foucault M. *The Birth of the Clinic*. New York, NY: Random House; 1973.
3. Kroenke K. Symptoms in medical patients: an untended field. *Am J Med.* 1992;92(suppl 1A):3S-6S.
4. White AA, Panjabi MM. *Clinical Biomechanics of the Spine*. 2nd ed. Philadelphia, Pa: JB Lippincott; 1990.

chapter 1

Concepts of Functional Anatomy

The neuromusculoskeletal aspects of all 4 extremities and the spinal column are similarly involved and relate to a general concept. The central nervous system and the musculoskeletal systems are the 2 major systems primarily involved in having a response to changes in the environment. These 2 systems are supplied by an immediate available source of energy to complete their intended tasks. The problem that presents in the musculoskeletal system is that the force expended in every joint during daily physiological behavior may lead to impairment and disability from dysfunction if in any way normal function is altered.

Once a musculoskeletal task is intended, there evolves a sequence of neural activities that culminate into completion of the intended task (Figure 1.1). The ultimate task is accomplished by the articulations of the musculoskeletal system. These joints are present in all 4 extremities and the vertebral column,[1] and all have a similar mechanism to achieve the goal intended.[2]

All neuromusculoskeletal activities are performed in "patterns," which are encoded in the central nervous system. These patterns were originally considered to exist in the cerebral cortex in the premotor cortex, but it is now accepted that they exist also in the brain stem, cerebellum, and spinal cord.[3] The goal of the task probably originates within the cortex but is modified in the midbrain and cerebellum. The nerve impulses are transmitted to the spinal cord and then impulses are sent to the muscles that activate the joints (Figure 1.2). There is an instantaneous sensory feedback that informs the brain of the completion of the task and modifies the accuracy of the movement.

The motor cortex and the midbrain do not contain orderly maps of the neuromuscular patterns. These maps are complex mosaics of neurons that are constantly being remapped, exhibiting a distinct plasticity, indicating frequent modification by training and experience.[4-9]

Motor activity occurs in 2 stages: planning and execution. In either stage, the precise desired task is planned, but the details of its execution requiring the needed torques and muscular forces are not considered. These later stages of torque, force, duration, and specificity are executed in

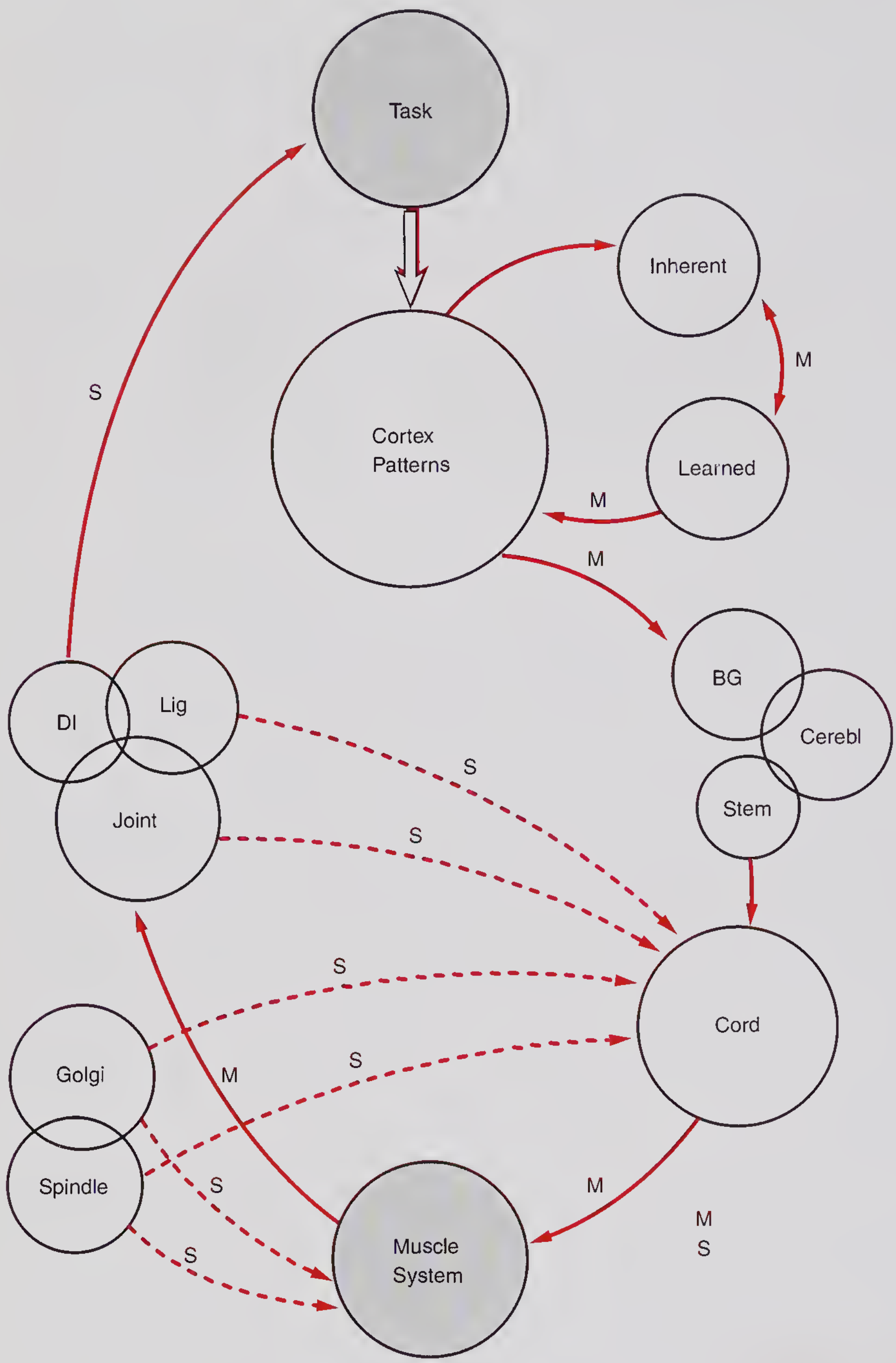


FIGURE 1.1

Neuromuscular Function After a task is contemplated, its performance is enacted in patterns that are encoded in central nervous system and that are inherent but modified by learning and training. Function that evolves through transmission of impulses in spinal cord to muscular system activates articulations. BG indicates basal ganglion; Cerebl, cerebellum; M, motor; S, sensory; Lig, ligament; and DI, disc (intervertebral).

the more distal musculoskeletal systems in the proposed sequence. The question raised by numerous neurophysiologists is, Does the brain represent movement? The answer is that movement is only minimally represented in the brain.

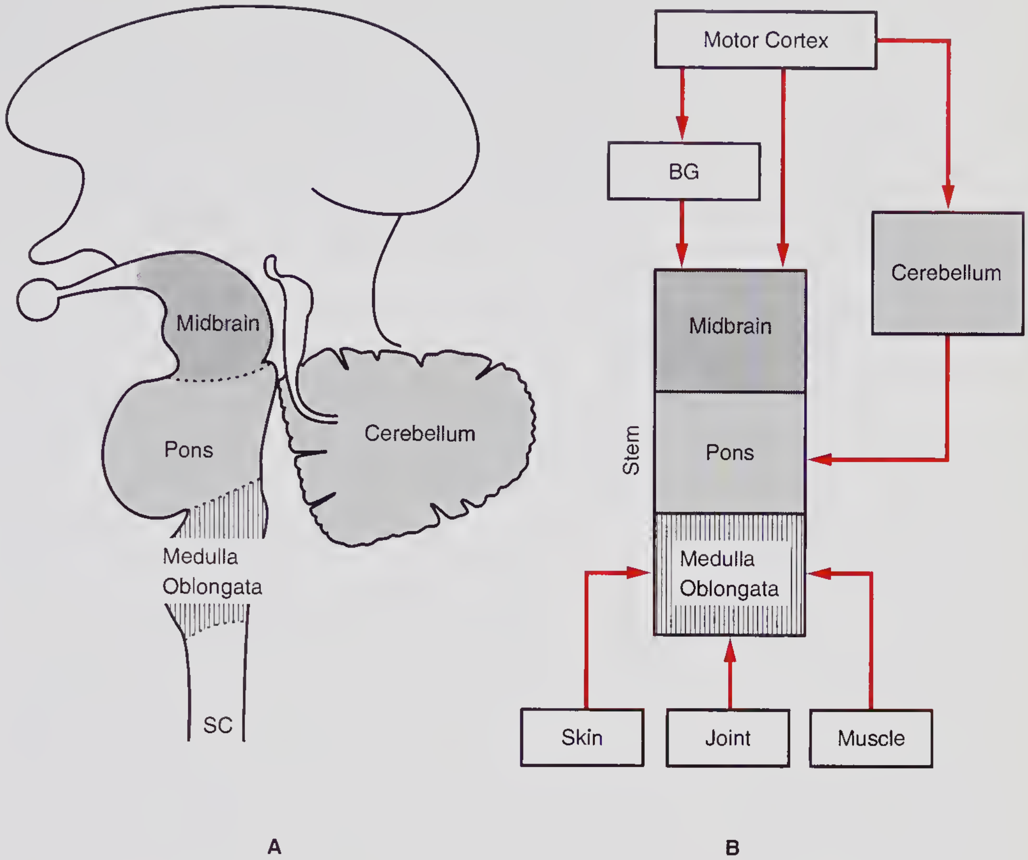


FIGURE 1.2

Subdivision of the Brain Stem A, Gross anatomy of brain stem. SC indicates spinal cord. B, Function of brain stem. BG indicates basal ganglion.

Musculoskeletal movement is a complex action, requiring cortical, midbrain, brain-stem, spinal cord, and musculoskeletal interaction to accomplish the desired task with greatest efficiency and minimal expenditure of energy. The cerebellum initially was considered as controlling single-joint actions; it now is considered to fine-tune complex motor skills involving numerous joints acting synchronously, as all movements do.[10]

PATTERNS

All neuromusculoskeletal actions are performed in patterns that involve multiple joints and in multiple directions simultaneously and with varying forces. There are no simple individual planes of motion but rather multiple motions about changing axis. Motion about an axis requires both isometric and isokinetic neuromuscular activity and agonist-antagonist interaction.

Usually, motion termed flexion and extension is rare, if ever exclusively present, as most motion of joints combines flexion-extension, lateral flexion, and rotation. This principle is true in every joint of the body. Most kinetic motion also occurs in rhythmic actions with various speeds and forces in simultaneous action. All these components need to be evaluated to establish patterns that apply to all joints of the body, whether they are joints of the extremity or of the spine.

MUSCULOSKELETAL FUNCTION

As shown in Figure 1.1, the muscles innervated by impulses from the spinal cord activate the skeletal muscles in both an isometric and isokinetic manner, with simultaneous agonist-antagonist contractions.

In an inactive extremity or the vertebral column, where gravity is a force to be controlled, the muscular system responds with adequate tonus.

MUSCULAR TONE

Muscle tone has been extensively studied and fully accepted yet remains unclear as to its mechanism. Muscles that maintain tonus are considered to be "silent," implying that they are not electrically active.[11-16] Basmajian[12] suggested that the usual definition of tone should be modified to state "that general tone of a muscle is determined by both passive elasticity and turgor of muscular tissues and fibrous tissues and that muscular contraction may not be continuous but is a response to the central nervous system to stimuli." This is a provocative yet sensible explanation of tonus.

Articular "stability" has been propounded for centuries and yet it and the role of muscle tone in stability are not fully understood. The intrinsic structures of any articulation—the capsules, cartilages, menisci, and disks in the spine—all are considered pertinent to ensuring stability of that joint if all these tissues are normal. Usually, however, the intrinsic tissues mentioned are inadequate to offer stability without the reinforcement of the muscular system.

The "relaxed" muscles of a static articulation considered to be electrically silent nevertheless have been found to have activity termed *tonus*, which is probably a "constantly varying tonic activity of the gamma loop system responding to external stimuli." General tonus as exhibited by electrical activity increases abruptly when a person sways from the center of gravity or an extremity such as the glenohumeral joint of the shoulder becomes active in abduction or forward flexion from the dependent position.

The extrafusal muscle fibers that become activated for any activity are determined from the supraspinal and spinal centers (Figure 1.3). All muscular functions are implemented by the extrafusal muscle fibers moderated as to force, speed, and extension of contraction by the intrafusal fibers and the Golgi apparatus (Figures 1.4, 1.5, 1.6, 1.7, 1.8).

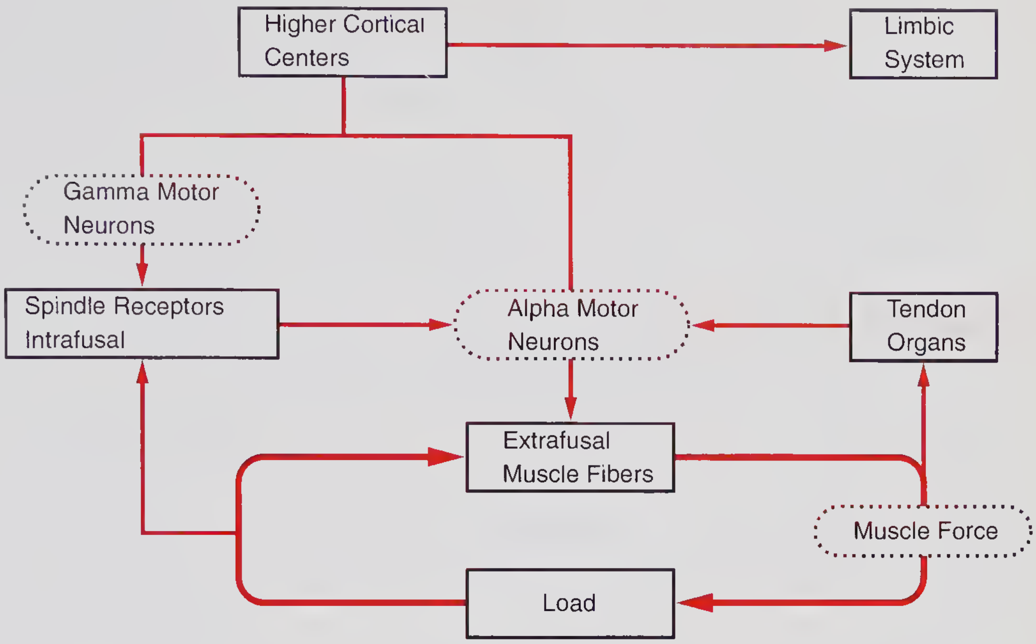


FIGURE 1.3

Spinal and Supraspinal Motor Centers Spinal and supraspinal motor centers show site of planning and motor execution from subcortical motor center to extrafusal muscle fibers. There is instantaneous sensory feedback.

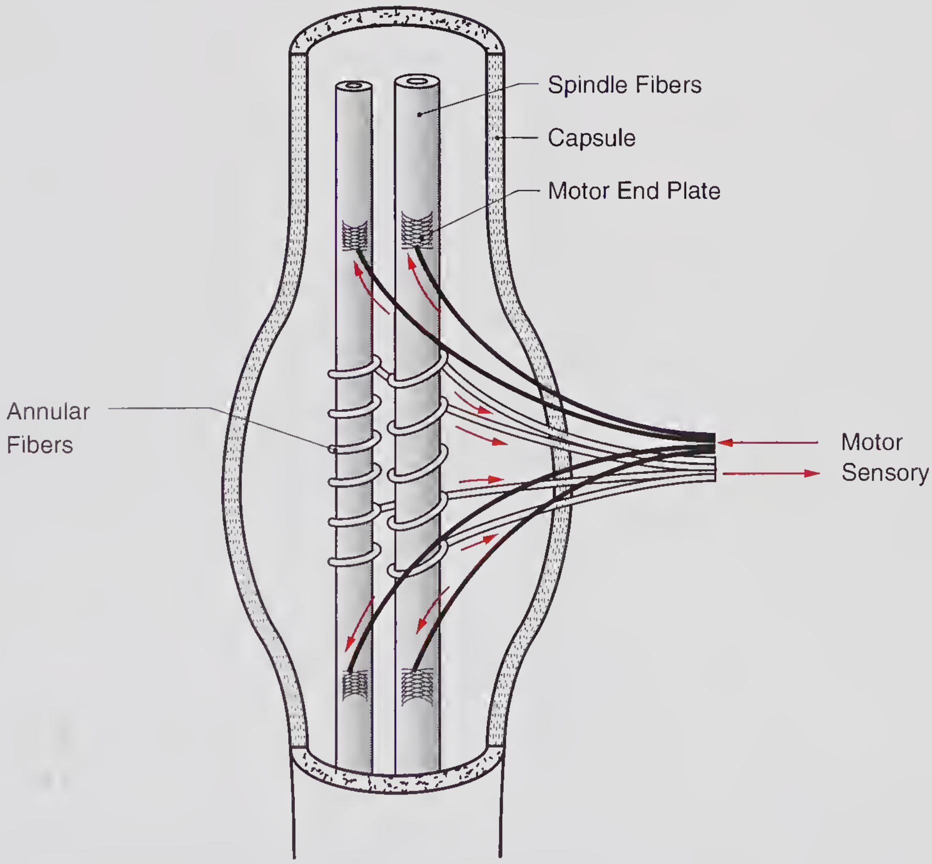


FIGURE 1.4

Muscle Spindle Simplified muscle spindle. Two intrafusal spindle fibers are enclosed within connective tissue capsule, which contains both motor and sensory fibrils. Motor fibrils innervate extrafusal muscle fibers.

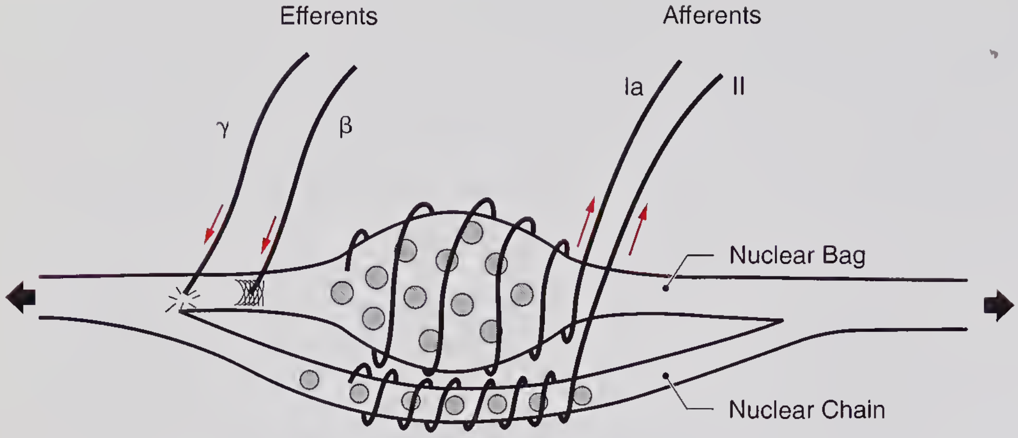


FIGURE 1.5

Innervation of Muscle Spindle Spindle system is composed of nuclear bag and nuclear chain. Both are subserved by afferent fibers Ia and II. Motor control of these components are gamma and beta efferent nerves that "reset" dynamics of spindle.

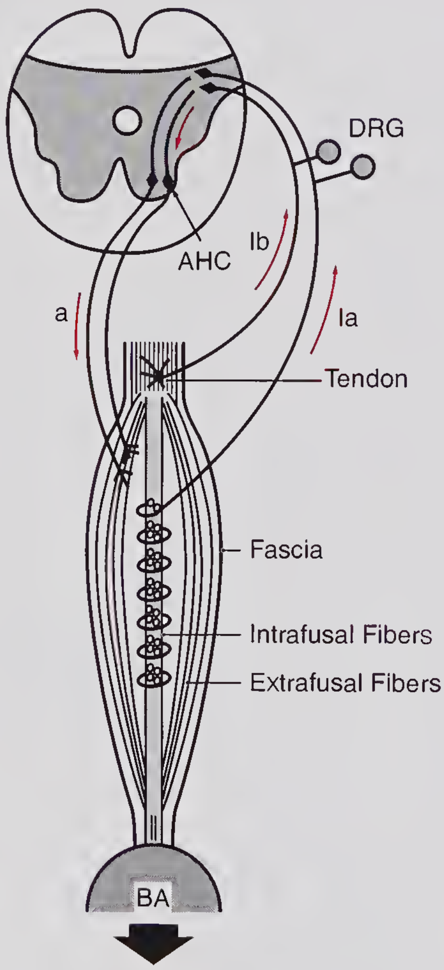


FIGURE 1.6

Spindle System Intrafusal (spindle) fibers lay parallel to extrafusal muscle fibers. When stretched, they signal spinal cord via Ia nerve fibers from spindle and Ib fibers from Golgi apparatus. These impulses pass through dorsal root ganglion (DRG) on their way to gray matter of spinal cord. From there, they send impulses to anterior horn cells (AHC), which innervate extrafusal muscle fibers. Fascia passively shortens or elongates with extrafusal fiber. BA indicates bony attachment of muscle fibers.

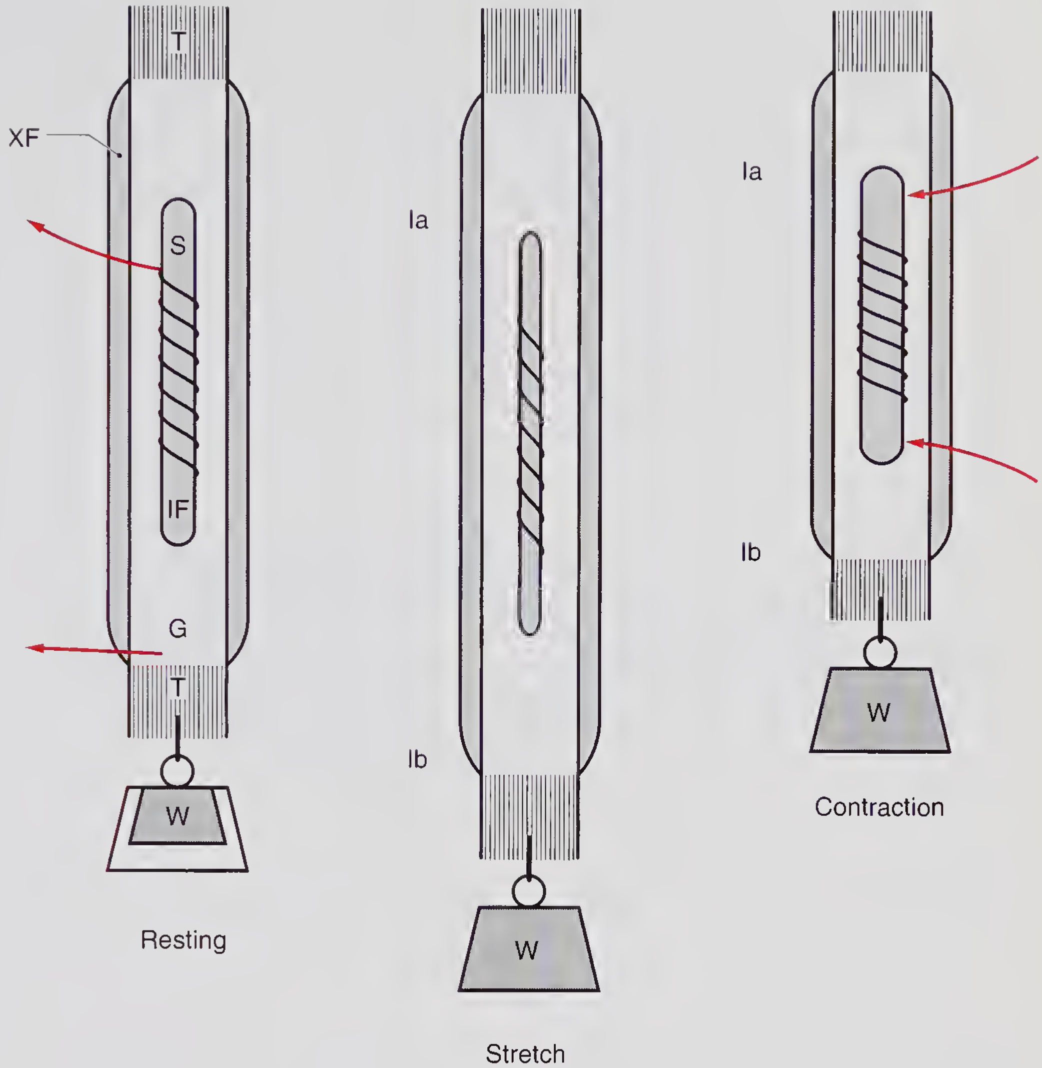


FIGURE 1.7

Mechanical Functional Alignment of Muscle Spindles and Golgi Apparatus Tendon In resting muscle, extrafusal fibers (XF) are quiet. Intrafusal fibers (IF) known as spindle (S) "report" to spinal cord via Ia nerve fibers as to length of extrafusal (and spindle) fibers. Tension (T) generated is "reported" to cord via Ib fibers emanating from Golgi apparatus (tendon organs) (G). In contracted extrafusal fibers lifting weight (W) greater than was supported at rest, all fibers contract. Spindle system is "reset" continuously via gamma fibers.

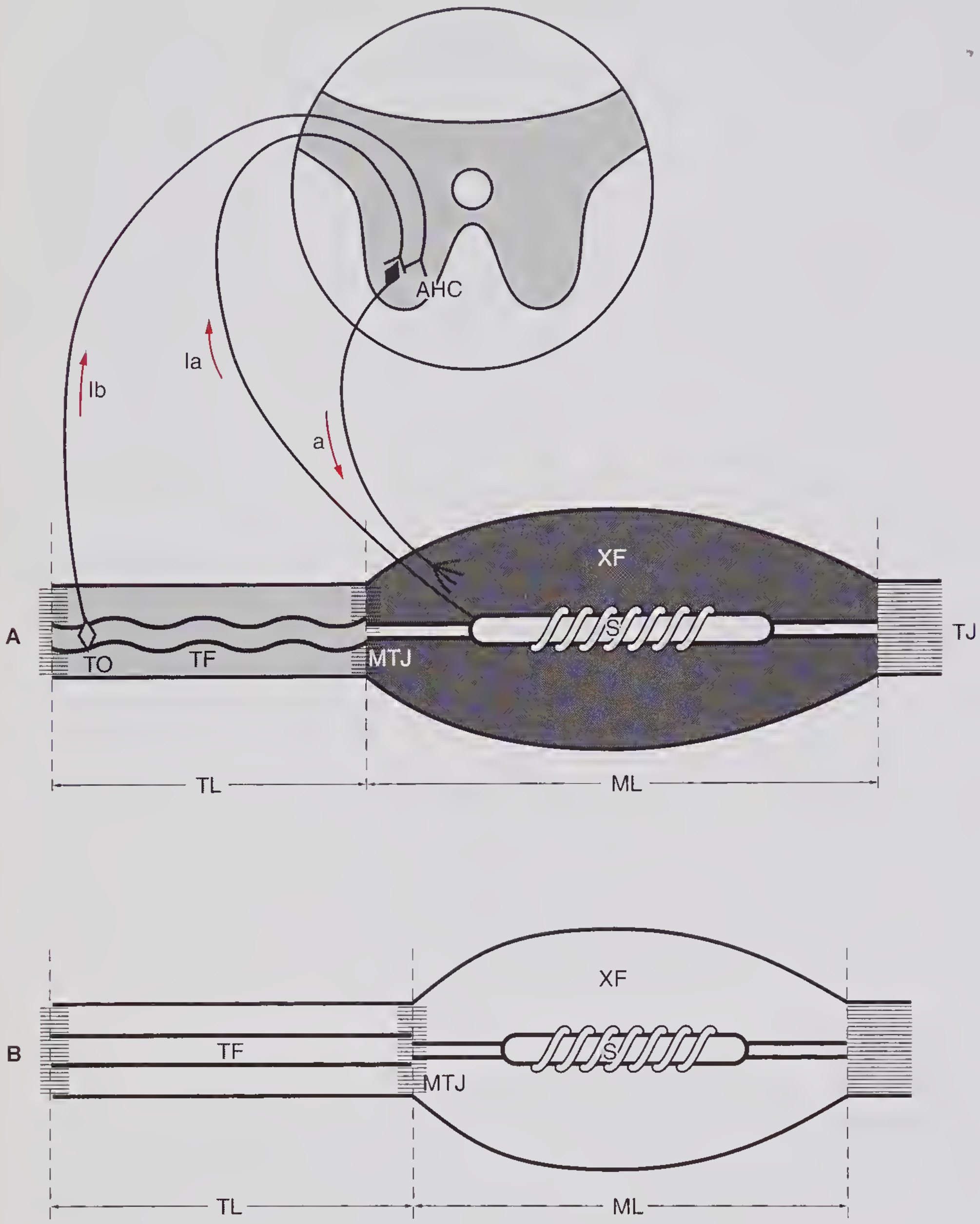


FIGURE 1.8

Musculotendinous Mechanism Spindle system (S) measures length of muscle fiber (ML), and tendon organ (Golgi apparatus, TO) monitors tension of fibers. Stretching spindle system activates Ia fibers, and activation of Golgi apparatus is via Ib fibers. Activated extrafusal (XF) response occurs through motor fibers of anterior horn cells (AHC) via alpha fibers. At rest (A), tendon fibers (TF) are slightly coiled, but when muscle contracts, tendon organs shorten (TL) and fibers increase their coiling. MTJ indicates muscle, tension joint; TJ, tension, joint.

MUSCLE CONTRACTION

A dissertation on functional neuromusculoskeletal anatomy would not be complete without revisiting the physiology of extrafusal muscle fibers. On activation, a nerve action potential originating at the anterior horn cell of the spinal cord travels along the afferent motor nerve, which ends on the

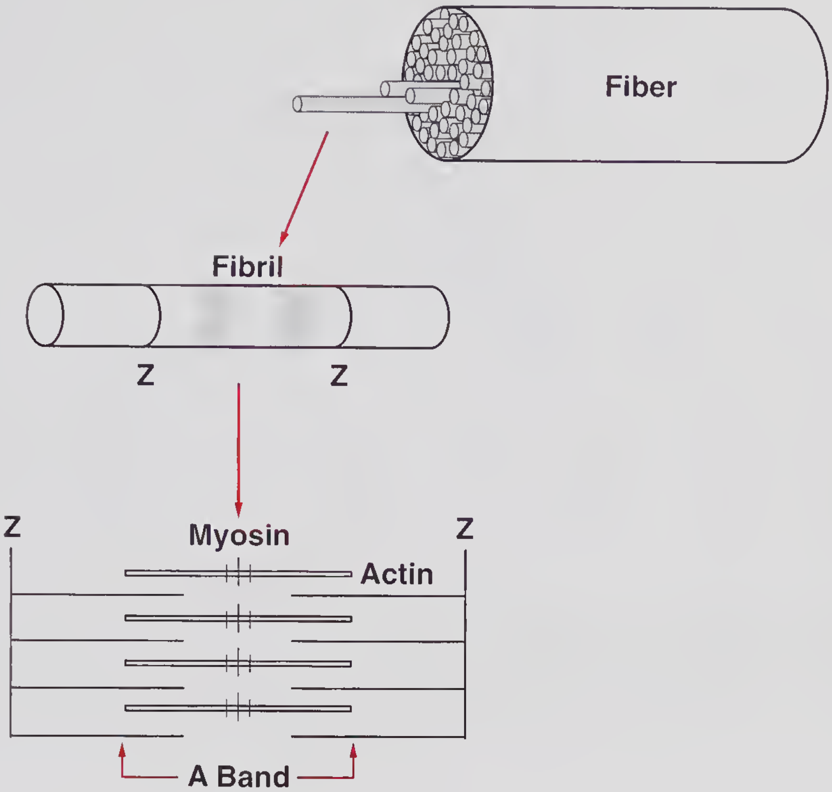


FIGURE 1.9

Organization of Skeletal Muscle: Extrafusal Fiber Within muscle fascicle, parallel muscle fibrils reside. These fibrils are parallel strands of myosin and actin, which glide on each other during contraction. Sarcomere is structure between 2 Z lines. A band is where actin and myosin interdigitate.

muscle fiber. At this myoneural junction, there is a terminal arborization on the surface of the muscle fiber (Figure 1.9). The axoplasm does not penetrate into the sarcoplasm of the muscle fiber but lies on its surface (Figure 1.10).

Each nerve fiber ending secretes acetylcholine, which is a neurotransmitter that opens acetylcholine protein channels within the membrane[17] (Figure 1.11). The subneural apparatus of the myoneural junction exhibits extremely high acetylcholine activity (Figure 1.12).

Calcium ions flow through these channels into the interior portions of the muscle, causing a contraction from the filaments gliding together[18] (Figure 1.13). What causes these filaments to slide on each other is a mechanical force generated by an interaction of the cross-bridges of myosin filaments with the actin filaments (Figure 1.14).

These forces are inhibited during rest, but when the action potential is delivered over the afferent motor nerve, a large amount of calcium is released.[19] The normal bond occurs because of adenosine triphosphate (ATP) and magnesium. In the presence of troponin-tropomyosin this bonding occurs (ie, the myosin filaments cannot attach to their pivot sites).[20,21]

The gliding is the result of attachment of the heads of the myosin filament to the site on actin which then chemically "rotates" causing the bridge to mechanically move the actin filament on the myosin filament

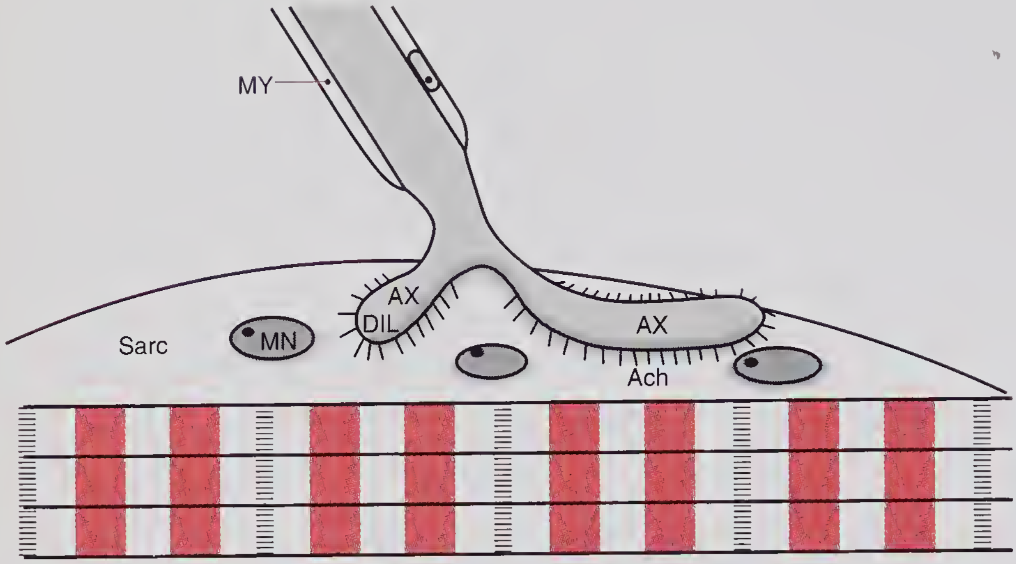


FIGURE 1.10

Myoneural Junction: Motor End Plate Terminal nerve branches onto a synaptic gutter under sarcoplasm (Sarc), where it deposits acetylcholine (Ach) that activates muscle fiber. This is subneural apparatus. A indicates axoplasm; AX DIL, axoplasm dilatation, which has small hair-like protrusions; MN, mitochondria; and MY, myelin sheath of axon.

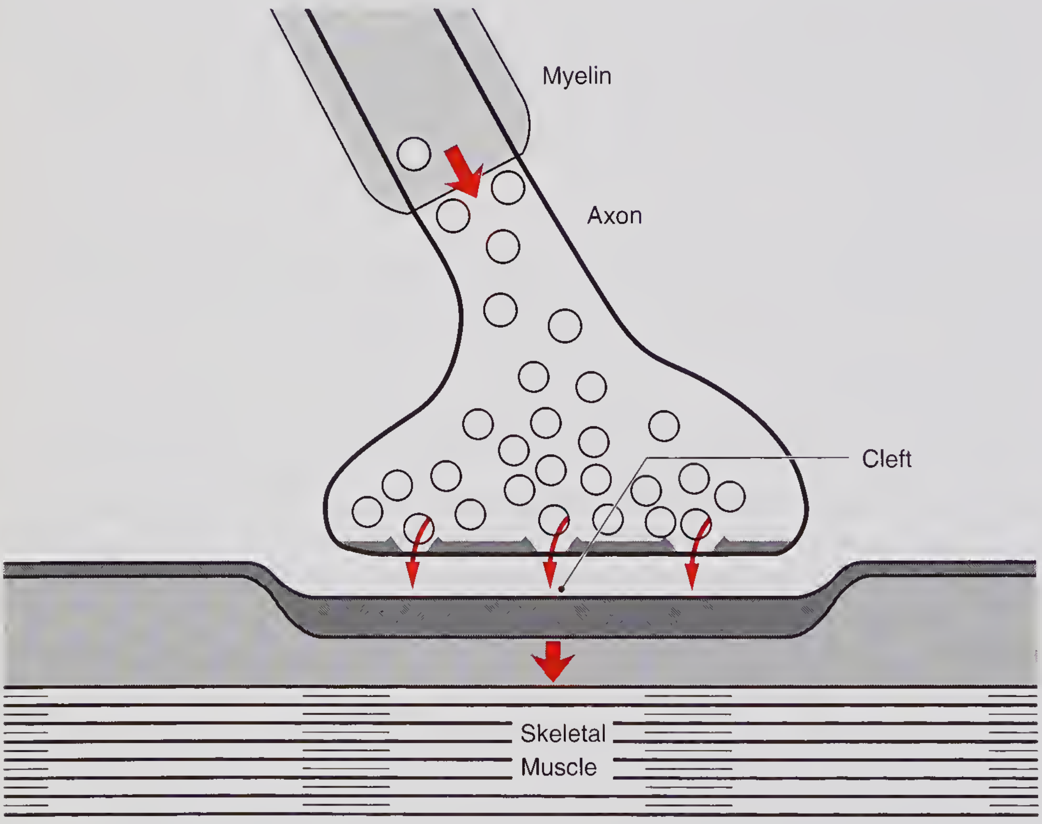


FIGURE 1.11

Neuromuscular End Plate Vesicles filled with chemical neurotransmitters descend (thick arrows) down axon, which is coated with myelin sheath. As the impulse passes from the "button" through the cleft (thin, curved arrows), it activates skeletal muscle fiber.

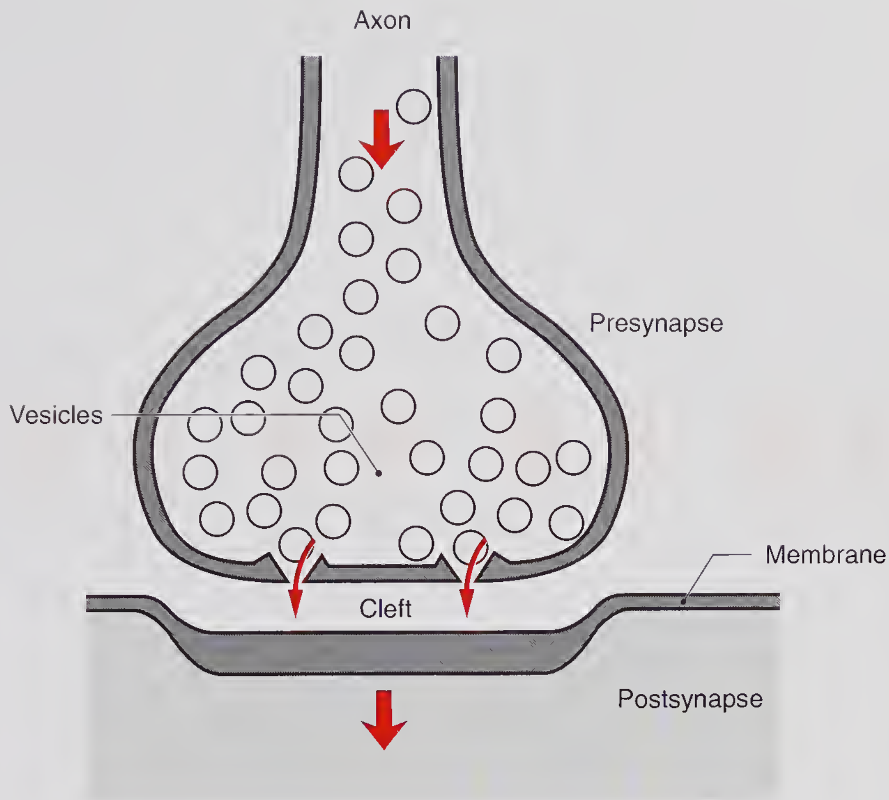


FIGURE 1.12

Chemical Synaptic Elements Presynaptic "button" secretes chemical in vesicles that transmit these chemical neurotransmitters, which leave the "button" and pass through the cleft (thin, curved arrows) to enter and stimulate postsynaptic receptor organ. Thick arrows indicate direction in which neurotransmitters move.

(Figure 1.15). Rotation of the myosin head is termed the "power stroke." The greater the number of cross-bridges that contract, the greater is the force of contraction.

The energy for muscular contraction is assumed to be cleavage of ATP to adenosine diphosphate (ADP). Before contraction, the heads of the cross-bridges contain ATP, which cleaves into ADP by adenosinetriphosphatase, furnishing the energy ultimately needed. Once the head of the myosin filament has rotated and caused a tilting of the bridge, the ADP is released. This allows the head to be released from the actin and reattached to a new site.

Effect of Tension on Muscular Contraction

The addition of tension to a muscle increases the tension that the contracting muscle can generate. If the muscle elongates before it contracts, the fibrils separate and overlap. There is no tension of the muscles until there is overlap. Tension increases proportionately with the overlap, reaching maximum tension with maximal overlap.

Tension within a muscle is determined by how many fibers contract, as all do not simultaneously contract. If a muscle is elongated to or past its physiological length, there is a "resting tension" before the muscle contracts due to elongation of the elastic forces within the connective tissues of the muscle bundle.

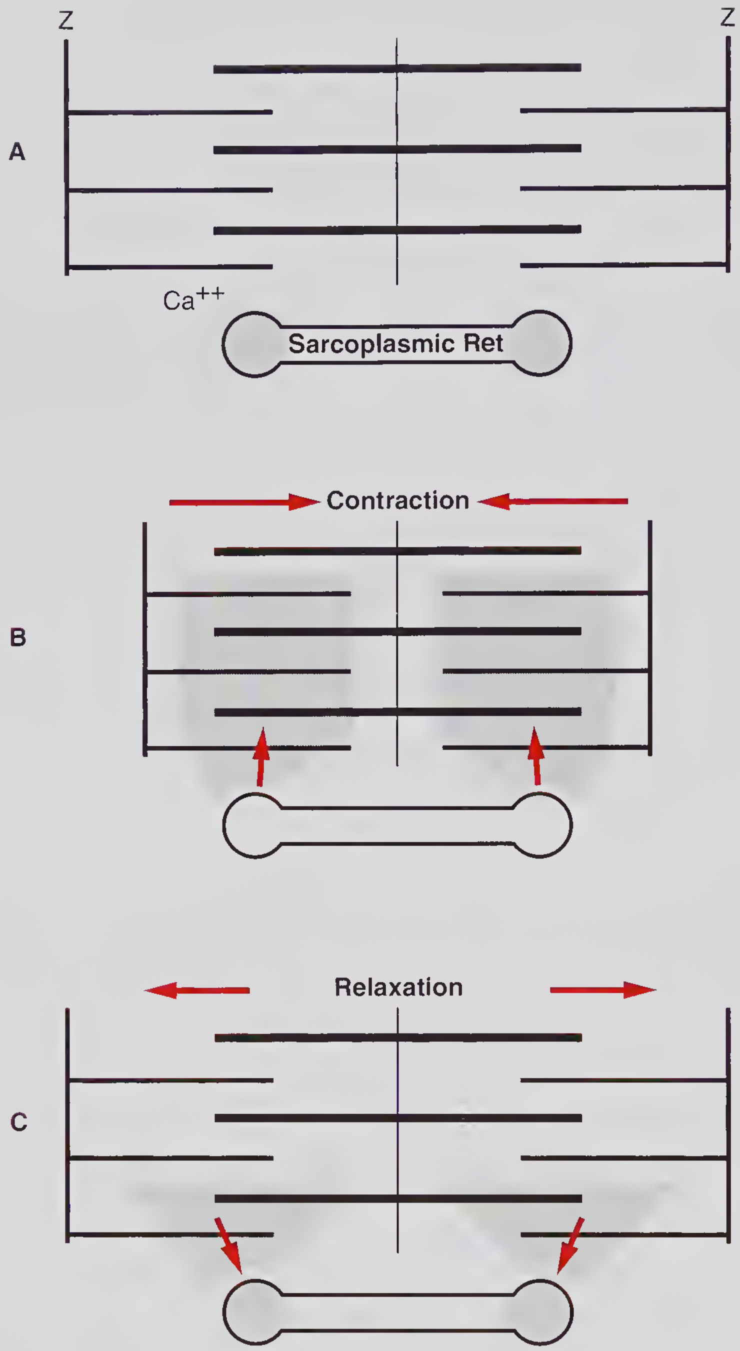


FIGURE 1.13

Contraction of Skeletal Muscle A, Relaxed muscle in which calcium (dotted area) is retained in sarcoplasmic reticulum (Ret). Thick lines indicate myosin, and thin parallel lines are actin. B, Myosin and actin glide on each other during muscle contraction, bringing Z lines closer together. C, As muscle relaxes, calcium is pumped into sarcoplasmic reticulum.

Characteristics of Muscle Contraction

A muscle that contracts without shortening is termed *isometric*. If it shortens, it is termed *isotonic* or *isokinetic*. The force of the contraction depends on the load and the distance to which the contraction is expected to occur. When a muscle contracts against a load, there are portions of the muscle

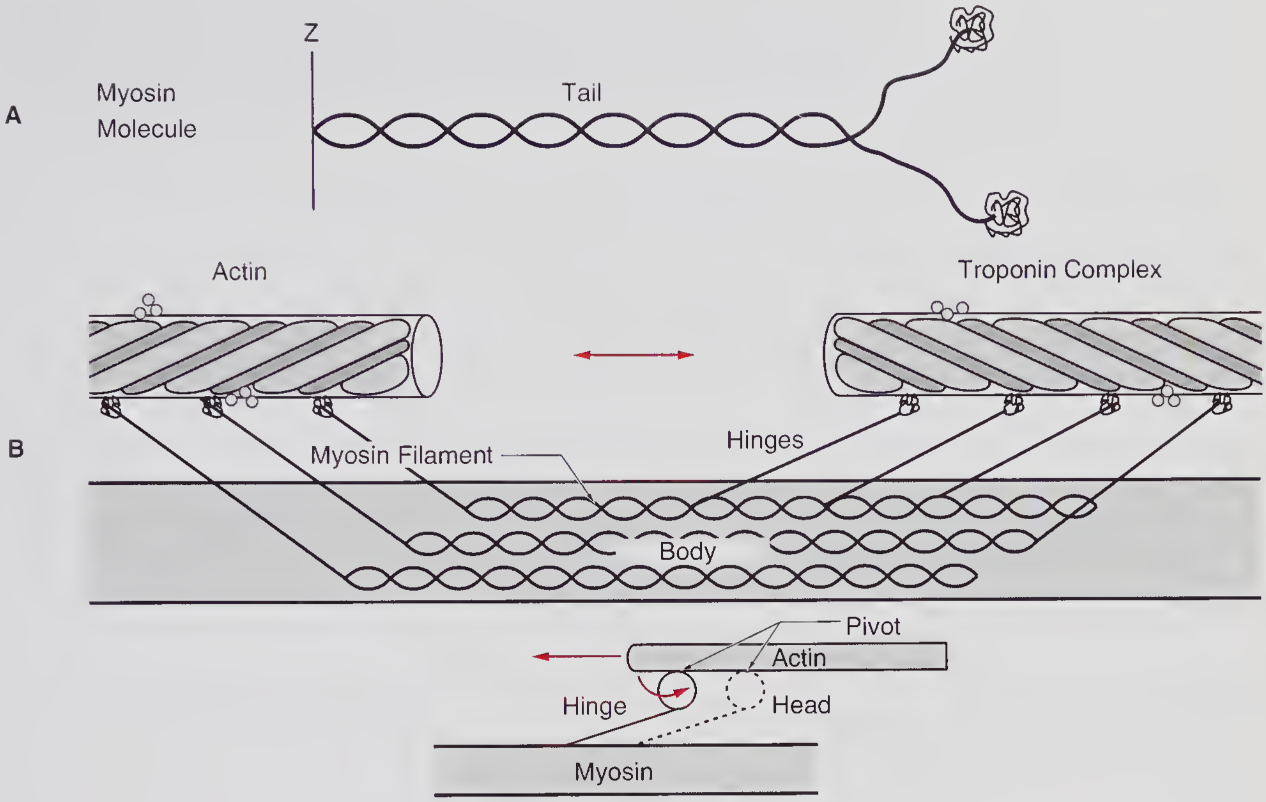


FIGURE 1.14

Mechanism of Muscle Contraction: A Concept Myosin molecule is a helix (2 protein chains), including a "tail" with a "head" (top of figure). Middle part of drawing shows myosin filament made up of as many as 200 molecules in a bundle, alternating with parallel actin filaments that are separate and glide on myosin. Dark strand of actin filament, which is a 2-strand helix, contains tropomyosin. Attached to tropomyosin molecule are troponin molecules. Actin filament and its troponin-tropomyosin complex inhibit activity. When calcium enters troponin-tropomyosin complex, it is neutralized and contraction begins. Contraction is assumed to occur about a pivot site (bottom part of figure), causing a "hinge" (myosin molecule tail-head filament) to slide (curved arrow) on actin filament. This action is called power stroke.

that do not contract. These tissues are the connective tissues of the muscle bundle, including its fascia and the conjoined tendon (Figure 1.16). The cross-bridges of the muscle also elongate and create tension. The total elongation of these tissues that influence the resultant force is called the *series elastic component* of a muscle contraction.

Skeletal muscles are constantly being "remodeled" in regard to their force, velocity, angulation, and recruitment to conform to their intended task. Their diameters, length, strength, and vascular supply are all altered. It has been postulated that the contractile proteins of muscles are replaced every 2 weeks.

Increase in muscle mass is termed *hypertrophy*, and decrease in muscle mass is called *atrophy*. The former results from an increase in individual muscle fibers, which occurs from contraction at a maximum force with simultaneous stretch (tension) during contraction. Myofibrils split to form new fibrils, which account for hypertrophy. The enzyme system that provides glycolysis also increases.

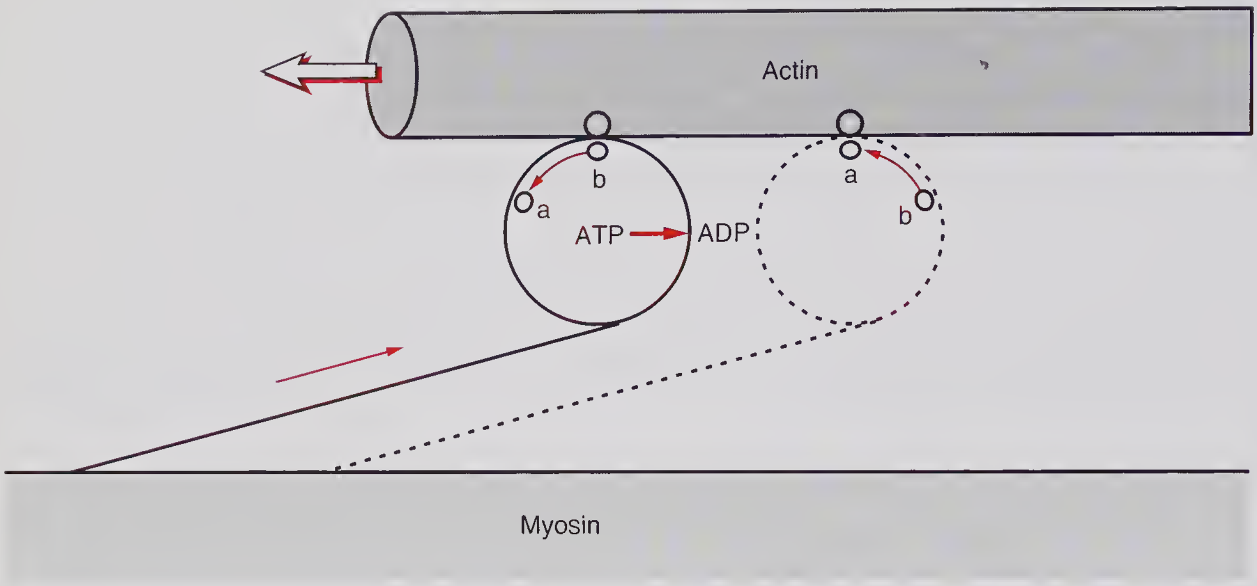


FIGURE 1.15

Movement of Head of Myosin Filament Head of myosin filament (dotted circle) shows (a) being attached to pivot site on actin filament. As head rotates (b), it ultimately attaches to pivot site. Rotation causes tension on bridge, causing actin filament to glide. Adenosine triphosphate (ATP) cleaves into adenosine diphosphate (ADP), furnishing energy for this muscular activity.

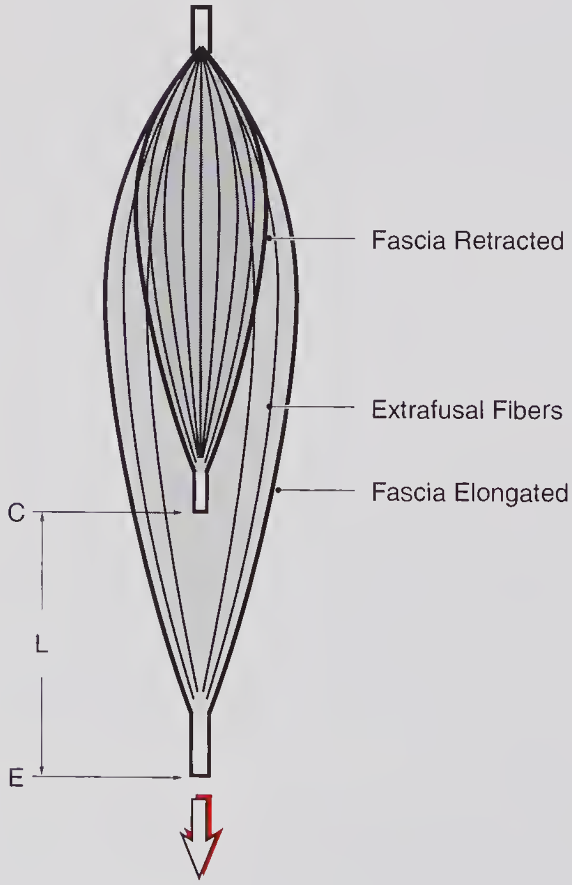


FIGURE 1.16

Muscle Fascial Characteristics A muscle bundle can elongate to extent that its fascial sheath will permit. Tension is invoked upon elongation of this sheath. Extrafusal fibers of the muscle elongate actively, whereas fascial sheath elongates passively (E) and shortens passively as muscle contracts (C). L indicates physiological length of muscle bundle.

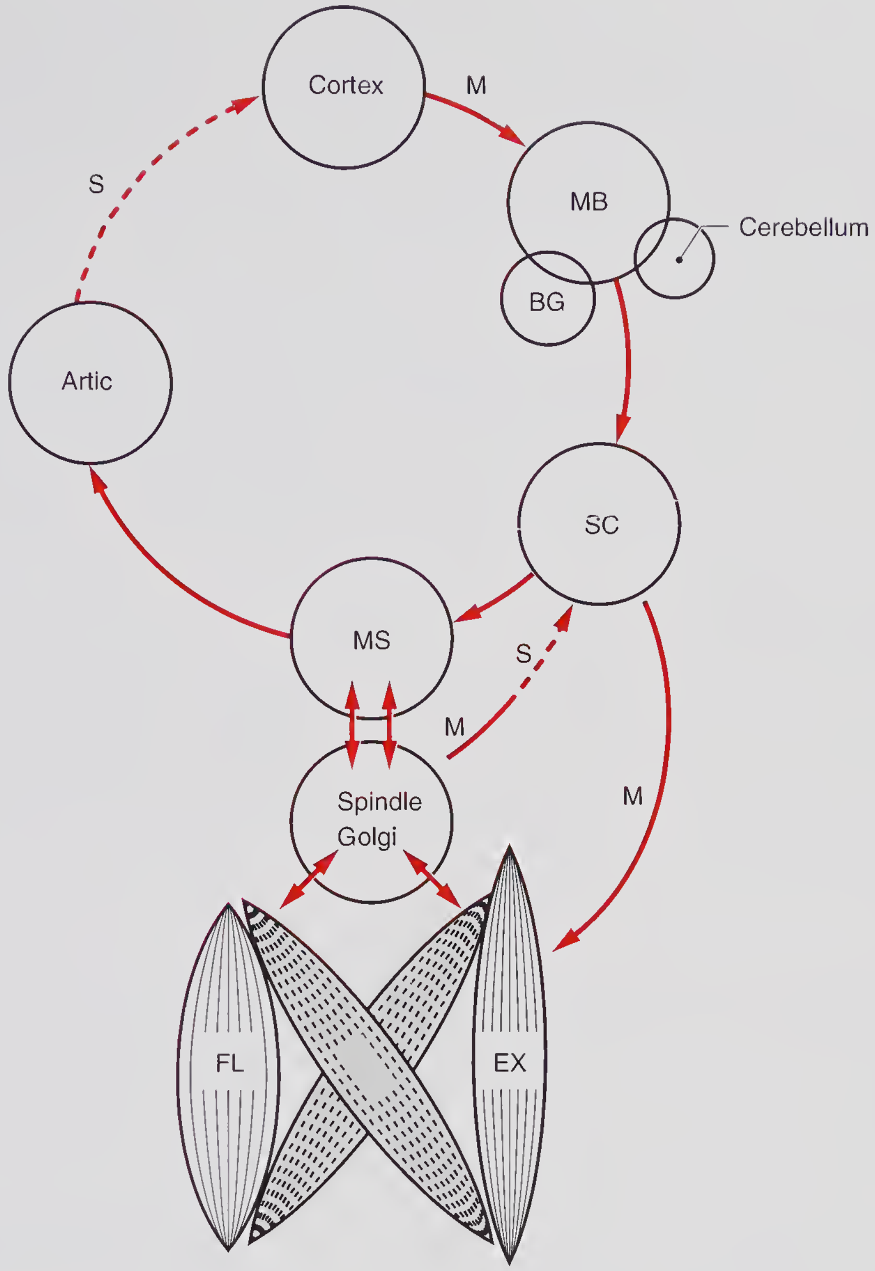


FIGURE 1.17

Co-Contraction of Agonist-Antagonist Muscles Neurologic sequence of muscular contraction. "Idea" is initiated at cortex level, moderated at brain stem, and proceeds to spinal cord (SC), where muscles (MS) are activated. Flexors (FL) (agonist) and extensors (EX) (antagonists) are moderated by spindle systems. M indicates motor; S, sensory; MB, midbrain; BG, basal ganglion; and Artic, articulation.

Muscular contraction to accomplish completion of any "task" encompasses contraction of the agonist with simultaneous contraction of antagonist muscle groups[22-30] (Figure 1.17). More will be described about the neuromuscular systems as each extremity and the vertebral column is discussed.

COLLAGEN

The building stone of structure and the basis of function is collagen, which is also the building stone of most, if not all, the soft tissues of the body (Figure 1.18). The collagen fiber is fundamental in understanding the

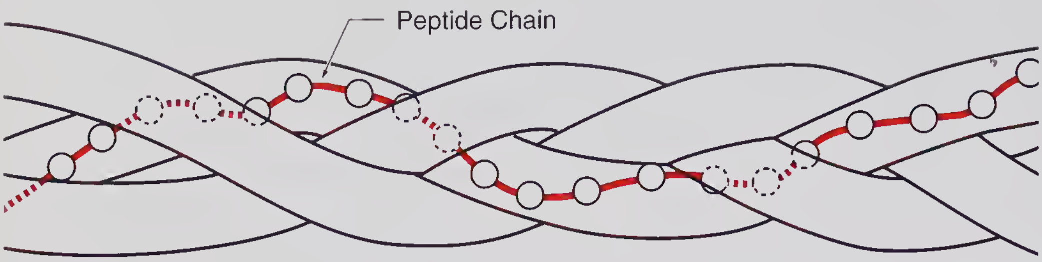


FIGURE 1.18

Collagen Fiber Type I collagen molecule is composed of peptide chains that include 1 α-2 and 2 α-1 peptide chains, in which every third molecule is a glycine amino acid. Three intertwining peptide chains form a trihelical collagen fiber.

structure and function of tendons, cartilage, menisci, and especially the intervertebral disk.

Collagen fibers are coiled chains of amino acids held together chemically and electrically. Collagen fibers make up ligaments, tendons, disk annular fibers, components of cartilage, and skin, and are components of the other soft tissues of the body.

Ligaments are parallel rows of collagen fibers that have limited elongation and can be stretched 6% to 8% of their length at rest[31] (Figure 1.19). As with muscle function, the collagen fibers will again be discussed specifically with each extremity and vertebral column entity.

ARTICULATIONS

Articulations (joints) are the end-organ in the proposed neuromusculoskeletal sequence being mobilized by muscles also in the sequence. By their planes, they determine the direction or directions permitted for that joint and also limit the direction and extent of that specific joint.

The understanding of joint mechanical function has been furthered by the association of the engineering profession with medical sciences. There are essentially 2 types of joint surfaces: ovoid and sellar (Figure 1.20). The ovoid is uniformly concave or convex, and the other surface within an articulation is convex in one plane and concave in the perpendicular plane.

The opposing curvatures in a joint also are considered as being congruous or incongruous depending on the arc or curvature and its relationship to the opposing surface[32-34] (Figure 1.21).

In a truly congruous joint, both opposing surfaces are identical in their curvature and there is equal contact at all points of the curves, which is feasible from engineering principles but functionally unacceptable in regard to lubrication. This would cause a "close-pack" relationship, causing the joint to bind, as no lubrication would be possible.[34] All joints must therefore be incongruous to a degree (Figures 1.22, 1.23).

Joints also may be classified as immovable (synarthrosis), slightly moveable (amphiarthrosis), or freely moveable (diarthrosis). Synarthrotic joints are 2 bone surfaces merely separated by an intervening membrane.

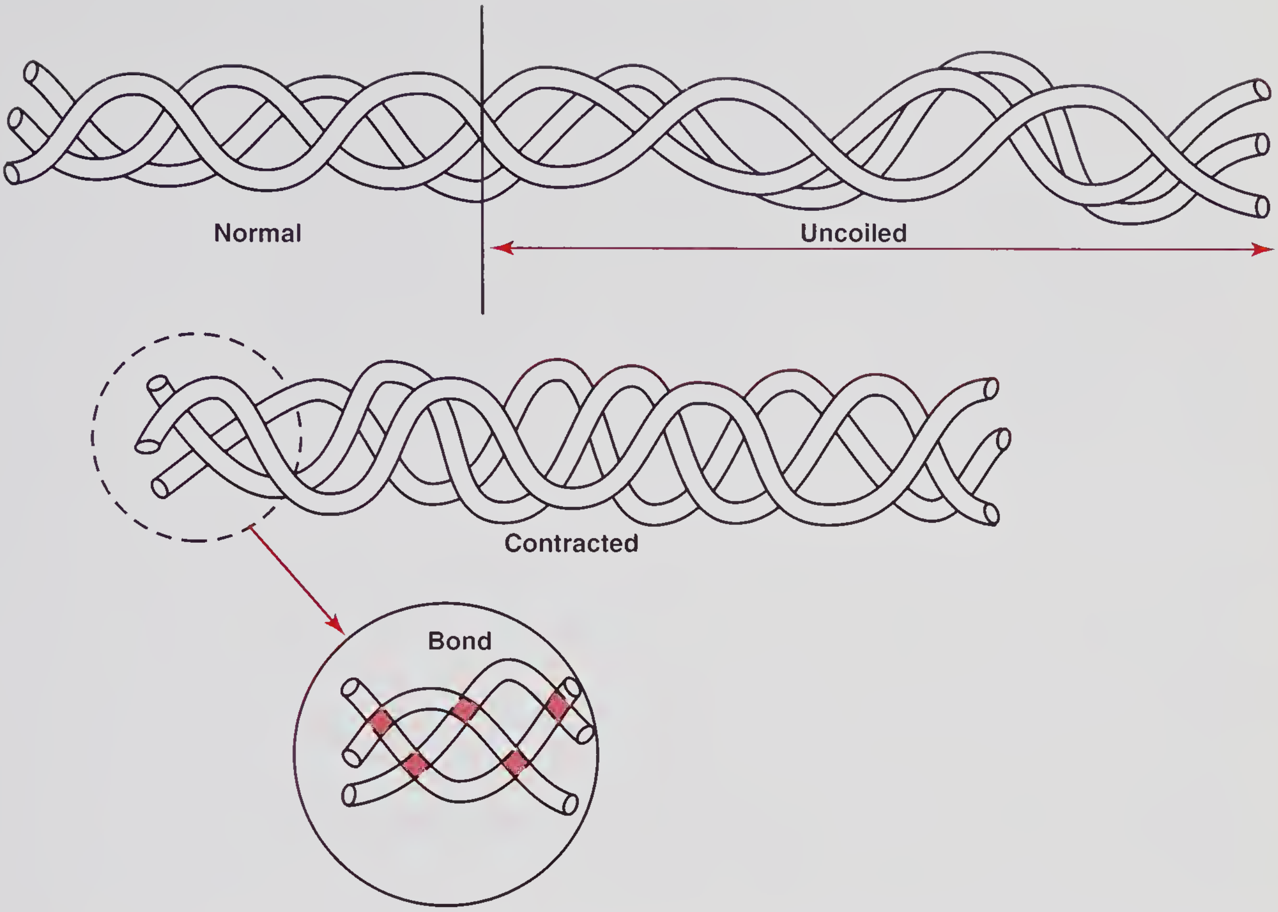


FIGURE 1.19

Collagen Fiber Elongation Collagen fiber at rest (normal) is coiled. Upon elongation (uncoiled), curl decreases, and with contraction (contracted), coils narrow. The trihelical fibers are bonded at each intersection. On release of any tension causing elongation, curls return to their physiological curling.

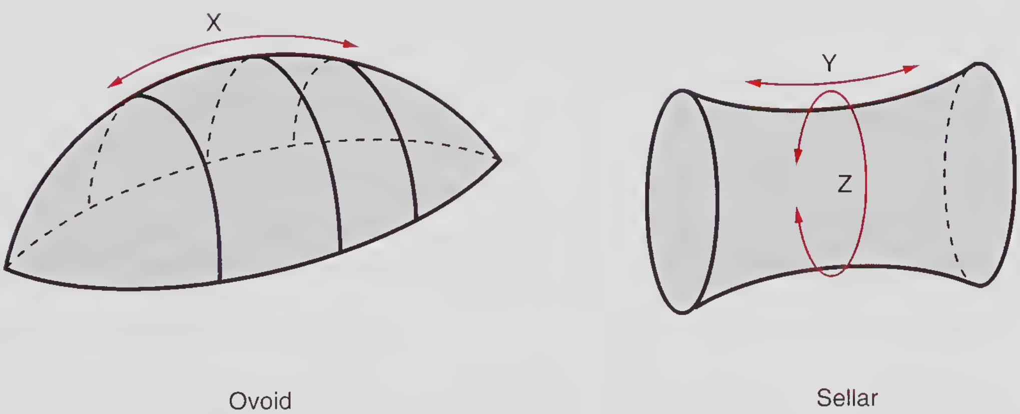


FIGURE 1.20

Joint Surfaces Two basic joint surfaces: ovoid and sellar. Ovoid is uniformly convex (X) at each point along surface. Sellar surface is convex (Z) in one plane and concave (Y) in perpendicular plane.

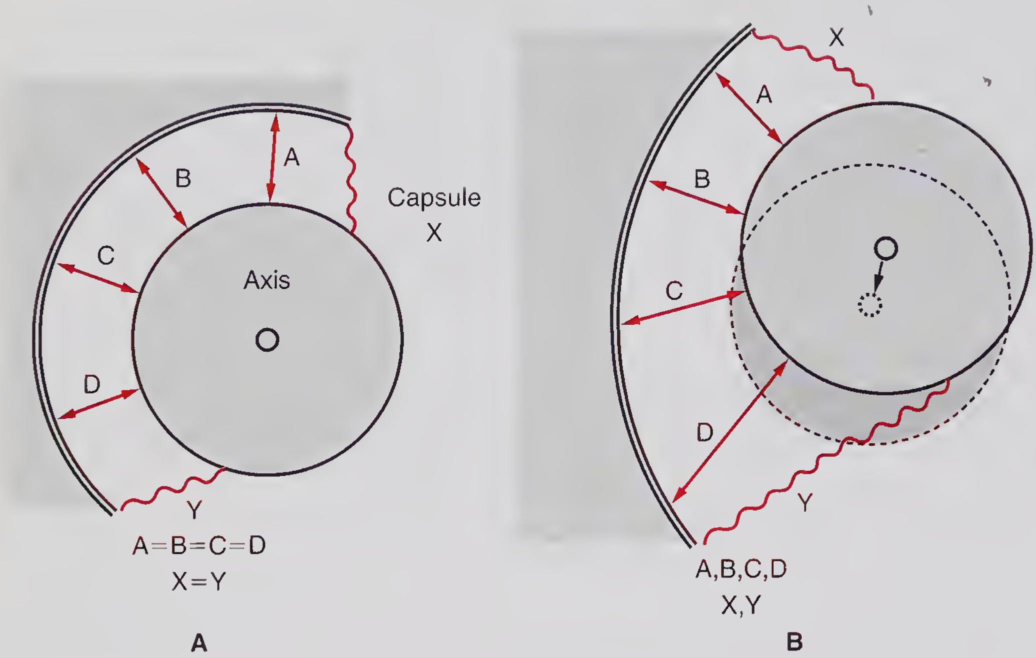


FIGURE 1.21

Congruity and Incongruity of Joints A, Totally congruous joint, where 2 articulating surfaces are symmetrically related and equally apart at all points: A = B = C = D. Axis of rotation remains at same site during rotation, and capsule is symmetrical. B, Incongruous joint with both surfaces asymmetrical (different curvatures). A, B, C, and D are not identical, and axis changes site during rotation and gliding.

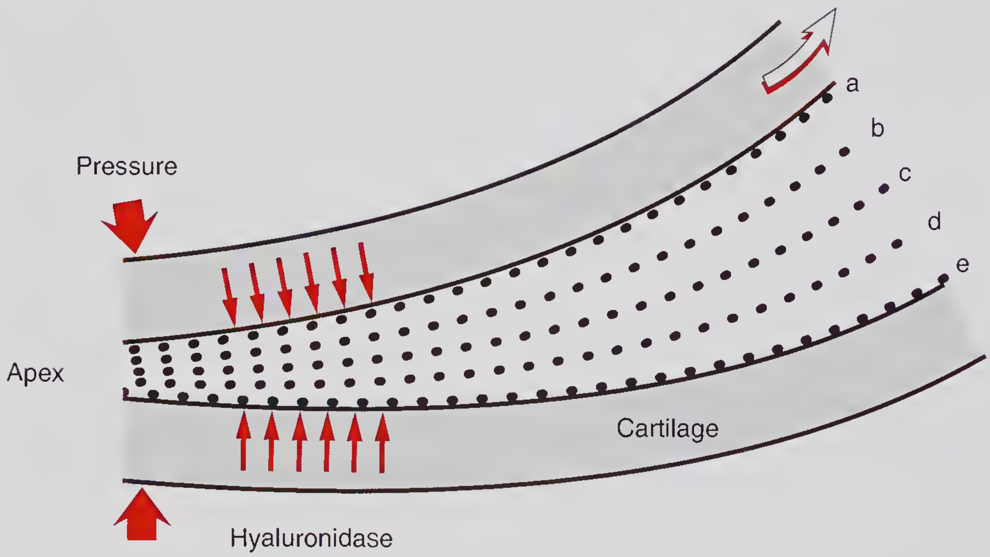


FIGURE 1.22

Lubrication of Joint Small molecules of lubricant (hyaluronidase) coat both surfaces of joint and are interspersed within joint (a, b, c, d, e). Curved arrow shows joint motion along with compression that sends lubricant from apex (contact) to wider portion of joint. Joint asymmetry is thus mandatory for adequate lubrication.

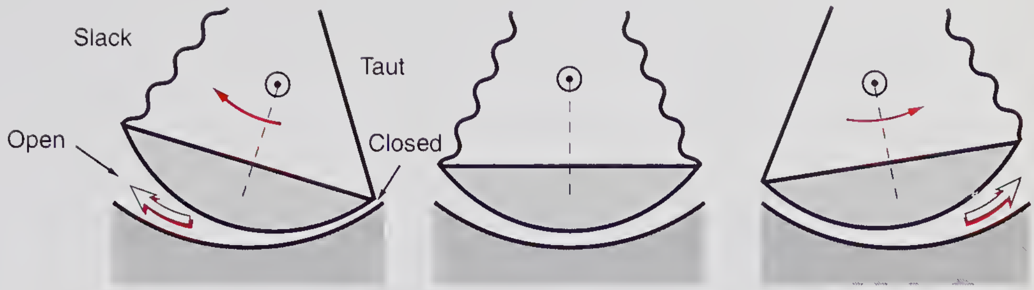


FIGURE 1.23

Asymmetrical Joint Surfaces Asymmetrical joint surfaces of incongruous joint cause synovial fluid (white curved arrow) to flow toward open joint space. Ligaments of joint remain taut on side away from rotation about the axis of rotation (circle with dotted line). Ligament and capsule become slack on opposite side.

Diarthrotic joints are articulations in which the opposing bony surfaces are covered by cartilaginous layers lined by a synovium. Joints also are classified according to their motion:

- enarthrosis (ball and socket),
- ginglymus (hinge),
- condyloid,
- trochoid (pivot),
- arthroid (gliding), or
- saddle.

Further definition of joints may include:

- gliding, in which one surface glides on the other in one direction without angular or rotatory motion;
- angular, in which the 2 opposing bones form a changing angle;
- circumduction, in which the opposing bones form an arc or circle into a cone; and
- rotation, in which one of the bones of the articulation moves about a central axis without moving away from this axis (Figures 1.24, 1.25).

Diarthrotic joints usually have a cartilage interface between opposing joint surfaces. Cartilage is needed for pain-free motion and for adequate lubrication. Cartilage also softens the impact on the joint (Figure 1.26). Cartilage is an avascular tissue that gets its nutrients from the vascular fluid in the subchondral bone (Figure 1.27).

Cartilage can take pressure and shear forces, provided it does not overcome the flexibility of the collagen fibers within its structure. Shear forces are the most damaging (Figure 1.28). Degradation of articular cartilage occurs from release of proteolytic enzymes from chondrocytes, synovial cells, and neutrophils.[35-38] These proteinases are termed *collagenase* when they destroy collagen, *stromelysin* as they destroy matrix, and *neutrophil elastase* as they destroy elastin.

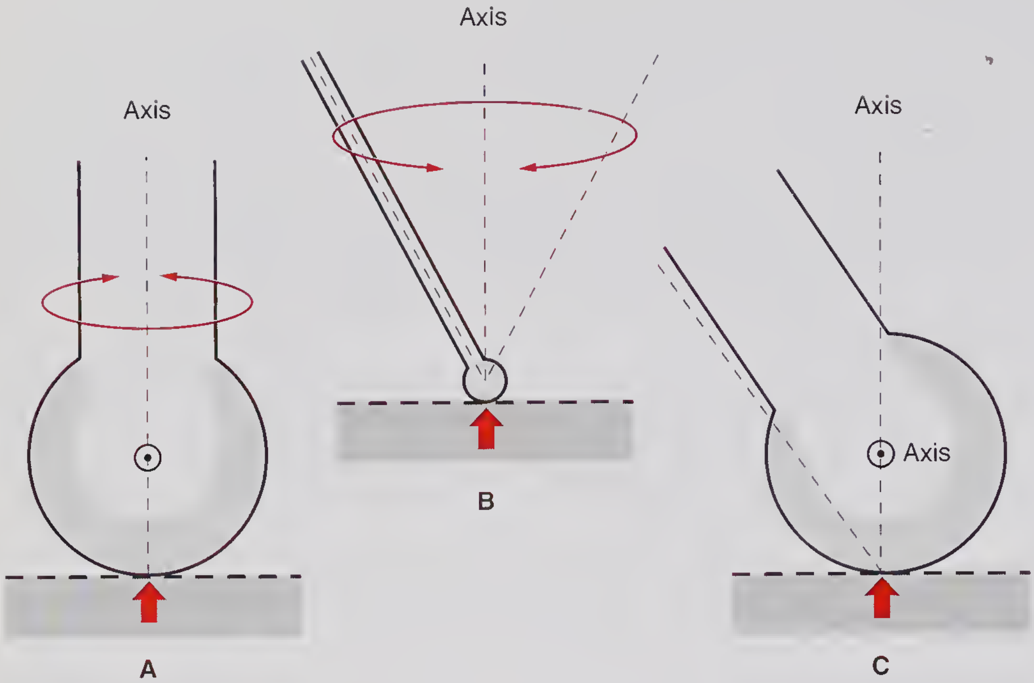


FIGURE 1.24

Joint Motion: Spin or Rotation True spin is exemplified in a top spinning about one point (A). If there is change in perpendicular axis (B) during spinning, spin-rotation (C) occurs.

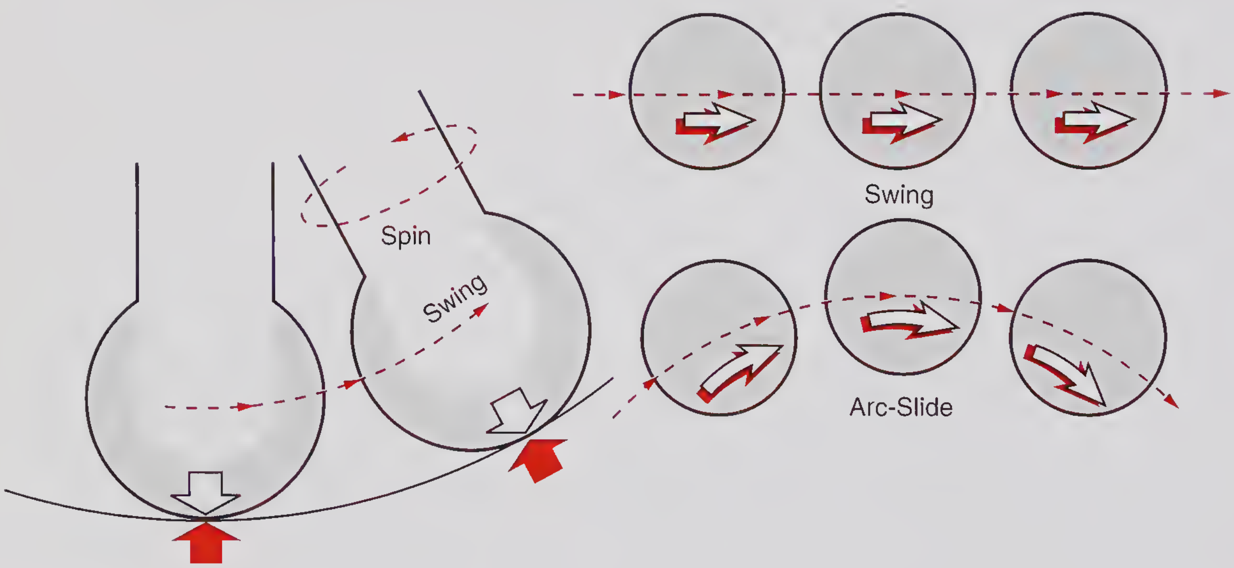


FIGURE 1.25

Joint Motion Sliding joint moves in one plane, which is called swing. There is no rotation or spin. If there is simultaneous rotation, motion is called arc-slide.

Pressure on cartilage expresses hyaluronidase, which is a lubricant that minimizes friction and acts as an adhesive keeping the opposing articular surfaces together.

Degenerative changes that occur in cartilage are considered to occur from several forces: (1) longitudinal forces—shear that occurs from external

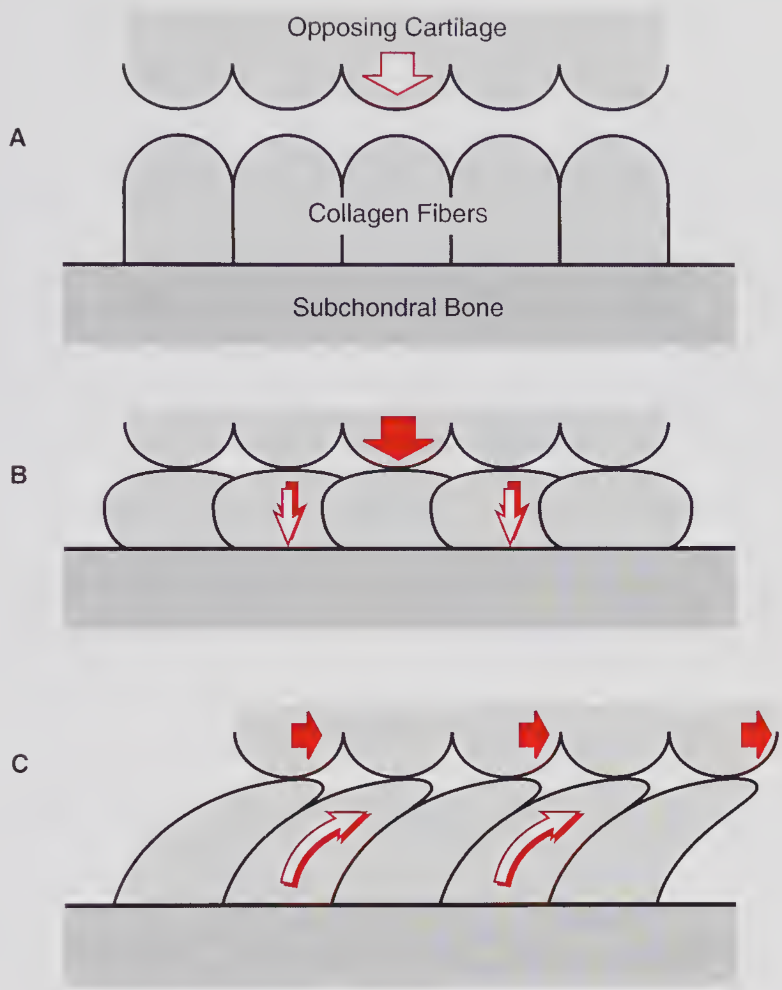


FIGURE 1.26

Cartilage A, Cartilage with its collagen spiral fibers, which act as springs. B, Effects of pressure on cartilage, which compresses collagen spiral fibers. C, Effects on cartilage from translatory (shear) forces.

forces and muscular contractions, (2) nonphysiological (excessive) compressive forces on the cartilage, and (3) impact on the subchondral bone causing microfractures. Shear forces once considered predominant in cartilage degeneration have been questioned. In laboratory studies on animals, laceration to cartilage, considered a rare occurrence in humans, has revealed interesting findings in that the laceration down to the calcific plate causes a hemorrhagic bulge in the cleft, which becomes further vascularized by the subchondral blood vessels (Figure 1.29).

Lacerations of cartilage not reaching the subchondral bone do not progress or heal, which is what is postulated in the human cartilage. In damage to human cartilage, there is initially flaking of the superficial surface of the cartilage. Cysts form in the tangential layers, causing craters. Hyaluronidase and other enzymes enter these craters, damaging chondroitin, which is a major component of cartilage.

Degeneration of this superficial layer causes a loss of elasticity, as the ends of the loops are no longer functional. This decreases the release of the lubricating fluid, permitting greater friction of cartilage on cartilage during

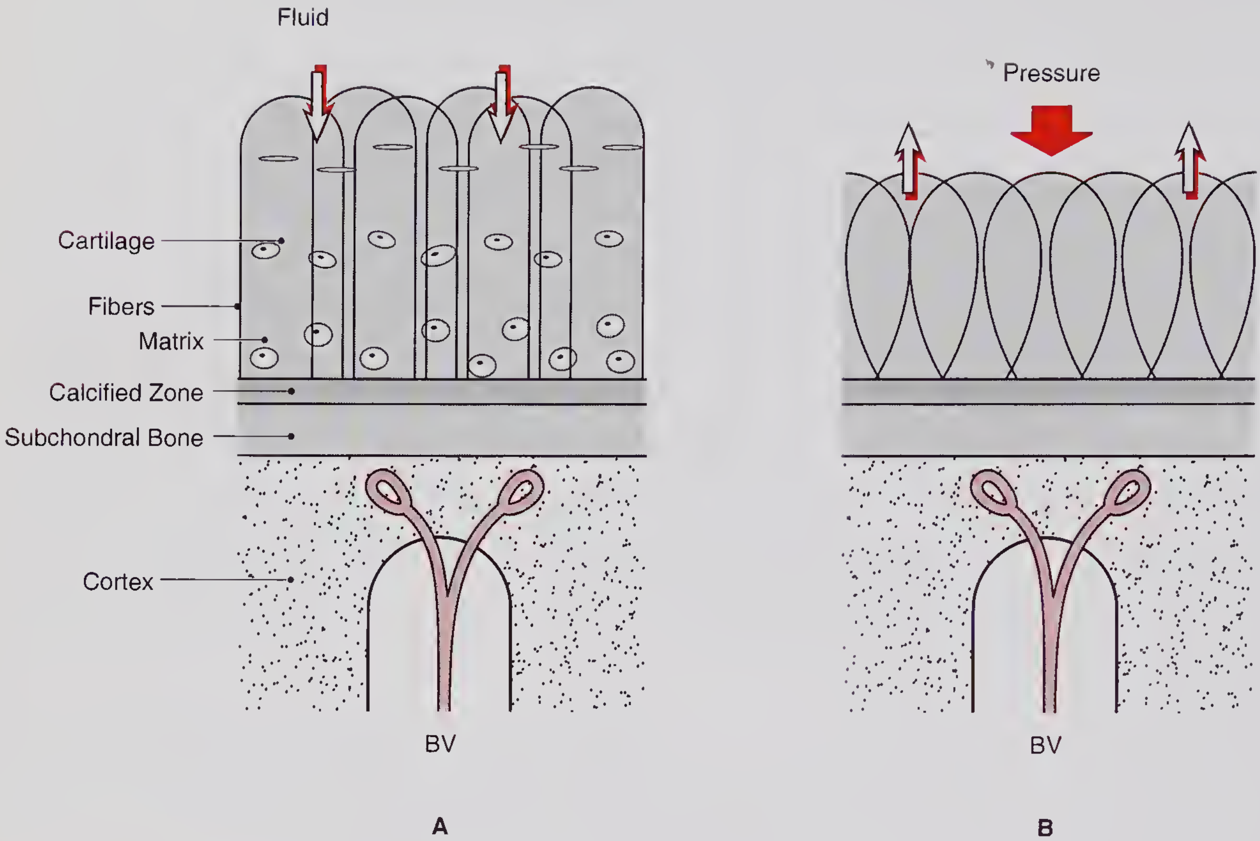


FIGURE 1.27

Nutrition of Cartilage A, Cartilage imbibes vascular fluid from terminal blood vessels (BV). B, Pressure (solid arrow) causes lubricating (synovial) fluid to exude into capsule (open arrows).

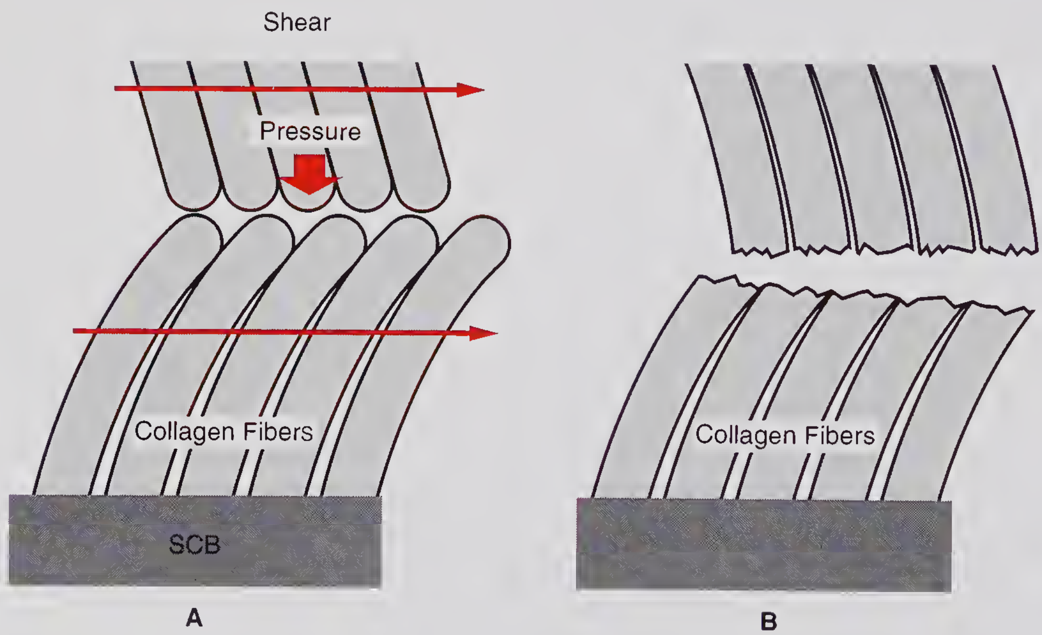


FIGURE 1.28

Damage from Shear Pressure to Cartilage A, Shear and pressure forces on cartilage. SCB indicates subcortical bone. B, Severance of tips of collagen coils within cartilage as a result of excessive pressure, especially shear.

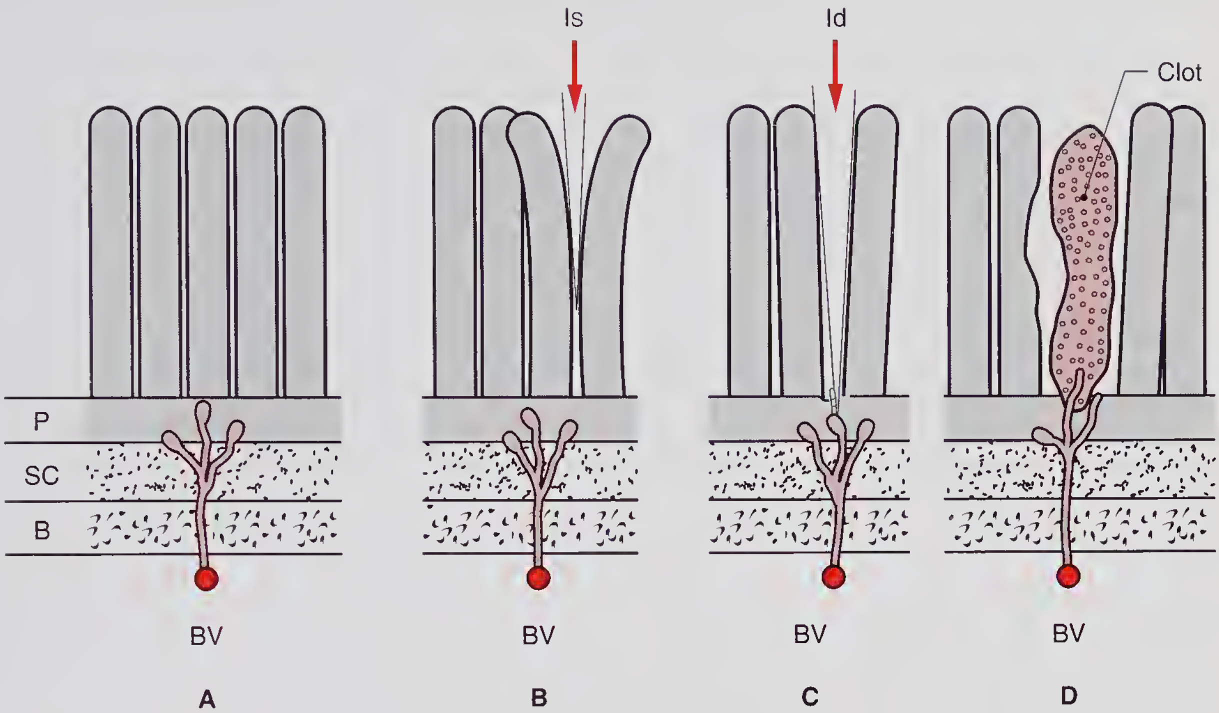


FIGURE 1.29

Response of Cartilage to Trauma A, Normal cartilage. P indicates calcified plate; SC, subchondral plate; and B, bone. Blood vessels (BV) penetrate into calcified plate but end as terminal bulbs. B, Sustained laceration (Is), which does not reach calcified plate. C, Laceration (Id) reaches and penetrates calcified plate. D, Formation of blood clot, which is penetrated by merging blood vessels (BV).

normal motion. The blood vessels in subchondral bone send fibroblasts into the crevices, gradually forming bone, which then proceeds to bone articulating against bone, rather than cartilage against cartilage.

With all these specific tissue changes in neuromusculoskeletal functional activities, it should lay the basis for changes that occur in specific neuromusculoskeletal clinical conditions. These conditions cause dysfunction and often pain, which will be discussed in subsequent chapters.

REFERENCES

1. White AA, Panjabi MM. *Clinical Biomechanics of the Spine*. 2nd ed. Philadelphia, Pa: JB Lippincott; 1990.
2. Farfan HF. Form and function of the musculoskeletal system as revealed by mathematical analysis of the lumbar spine. *Spine*. 1995;20:1462–1474.
3. Raymond JL, Lisberger SG, Mauk MD. The cerebellum: a neuronal learning machine. *Science*. 1996;272:1126–1131.
4. Bringa M. Remapping the motor cortex. *Science*. 1995;268:1696–1698.
5. Schott GD. Penfield's homunculus: a note on cerebral cartography. *J Neurol Neurosurg Psychiatry*. 1993;56:329-333.
6. Bernstein N. *The Co-ordination and Regulation of Movements*. Oxford, England: Pergamon Press; 1967.

7. Denier van der Gon JJ, Coolen ACC, Erkelens CJ, Jonker HJJ. Self-organizing neural mechanisms responsible for muscle coordination. In: Winters JM, Woo SL-Y, eds. *Multiple Muscle Systems: Biomechanics and Movement Organization*. New York, NY: Springer-Verlag; 1991.
8. Brooks VB. *The Neural Basis of Motor Control*. New York, NY: Oxford University Press; 1986.
9. Pennisi E. Tilting against a major theory of movement control. *Science*. 1996; 272:32-33.
10. Wickelgren I. The cerebellum: the brain's engine of agility. *Science*. 1998;281: 1588-1590.
11. deVries HA. Muscle tonus in postural muscles. *Am J Phys Med*. 1964;44:275-291.
12. Basmajian JV. *Muscles Alive: Their Function as Revealed by Electromyography*. Baltimore, Md: Williams & Wilkins; 1962.
13. Thomas JE. Muscle tone and spasticity. *J Nerve Met Dis*. 1961;132:505-514.
14. Ralston HJ, Lobet B. The question of tonus in skeletal muscle. *Am J Phys Med Rehabil*. 1953;32:85-92.
15. Kelton IW, Wright RD. The mechanism of easy standing by man. *J Exp Biol Med Sci*. 1949;27:505-515.
16. Jacobson EL. Innervation and tonus of striated muscle in man. *J Nerv Ment Dis*. 1943;97:197-203.
17. Scherrer J, Monod H. Le travail musculaire local et la fatigue chez l'homme. *J Physiol* (Paris). 1960;52:419-501.
18. Ecles JC. *The Physiology of Synapses*. Berlin, Germany: Springer-Verlag; 1964.
19. Ikai M, Yabe K, Ischii K. Muskelkraft und musculare Ermuedung bei willkuerlicher Anspannung und elektrischer Reizung des Muskels. Sportarzt Sportmed. 1967; 5:197-204.
20. Christensen EH. Muscular work and fatigue. In: Rodahl K, Horvath SM, eds. *Muscle as a Tissue*. New York, NY: McGraw-Hill; 1962.
21. Huxley AF. Muscular contraction. Annu Rev Physiol. 1988;50:1.
22. Grandjean E. Fatigue: its physiological and psychological basis. *Ergonomics*. 1968;11:427-436.
23. Panjabi MM. The stabilizing system of the spine. Part II: Neutral zone and instability hypothesis. *J Spinal Disord*. 1992;5:390-396.
24. Floyd WF, Silver PHS. Function of erector spinae muscles in flexion of the trunk. *Lancet*. 1951;133:143.
25. Kaigle AM, Wessberg P, Hansson TH. Muscular and kinetic behavior of the lumbar spine during flexion-extension. *J Spinal Disord*. 1998;11:163-174.
26. Lavender SA, Tsuang TH, Andersson GBJ, Hafezi A, Shin CC. Trunk muscles co-contraction: the effects of moment direction and moment magnitude. *J Orthop Res*. 1992;10:691-700.
27. Zetterberg DG, Andersson GBJ, Schultz AB. The activity of individual trunk muscles during heavy physical loading. *Spine*. 1987;12:1035-1040.
28. Thelen DG, Schultz AB, Ashton-Miller JA. Co-contraction of lumbar muscles during development of time varying tri-axial moments. *J Orthop Res*. 1995;13: 390-398.

29. Potvin JR, O'Brien PR. Trunk muscle co-contraction increases during fatiguing isometric, lateral bending exertions. *Spine*. 1998;23:774-780.
30. Crisco JJ, Panjabi MM. Postural biomechanical stability and gross muscular architecture of the spine. In: Winters JM, Woo SL-Y, eds. *Multiple Muscle Systems: Biomechanics and Movement Organization*. New York, NY: Springer-Verlag; 1991.
31. Tillman LJ, Cummins GS. Biological mechanisms of connective tissue mutability. In: Cummins DP, Nelson RM, eds. *Dynamics of Human Biological Tissues*. Philadelphia, Pa: FA Davis; 1992.
32. MacConnaill MA. Studies in the mechanics of synovial joints. *Irish J Med Sci*. 1946:21:223.
33. MacConnaill MA. The movement of bones and joints. *J Bone Joint Surg*. 1950; 32B:244.
34. MacConnaill MA. The movement of bones and joints. *J Bone Joint Surg*. 1951; 33B:251.
35. Polle AR. Enzymic degradation: cartilage destruction. In: Brandt KD, ed. *Cartilage Changes in Osteoarthritis*. Indianapolis, Ind: Indiana University School of Medicine; 1990.
36. Mankin HJ. The reaction of articular cartilage to injury and osteoarthritis. *New Engl J Med*. 1974;291:1335.
37. Johns RJ, Wright V. Relative importance of various tissues in joint stiffness. *J Appl Physiol*. 1962;17:825.
38. Coutts RD. Symposium: the diagnosis and treatment of injuries involving the articular cartilage. *Contemp Orthoped*. 1989;19:401.

chapter 2

Functional Anatomy of the Lumbosacral Spine

Before any painful disabling condition of the lumbosacral or cervical spine can be diagnosed and managed, normal spinal function must be clearly understood.[1] Only then can a medical history and physical examination be informative.

STRUCTURE AND FUNCTION OF THE SPINE

Static Spine

The erect spine is called the *static spine* or the *posture* (Figure 2.1). It consists of 4 physiological curves: lumbar lordosis, cervical lordosis, thoracic kyphosis, and sacral kyphosis. All conform to the center of gravity. The entire spine rests on the sacral base, whose angle determines the degrees of superincumbent curves[2] (Figure 2.2).

The spine is composed of functional units (Figure 2.3). The functional units of the vertebral columns are composed of 2 adjacent vertebrae separated by an intervertebral disk. The anterior portion is for support,[3] and the posterior is for gliding.

Lumbosacral Spine

The lumbosacral spine is composed of the lower 5 functional units (Figure 2.4). The lumbosacral spine bears on the sacrum and all adjacent vertebrae, which are separated by an intervertebral disk (Figures 2.5, 2.6, 2.7).

The intervertebral disk is a hydrodynamic elastic structure composed of mucopolysaccharide gel containing annular fibers; these fibers attach to adjacent vertebral end plates and obliquely cross each other in planes.[1,2] These annular fibers encircle the centrally placed nucleus. The nucleus pulposus is also a proteoglycan gel that contains random, aligned collagen fibers of type II.[4] Its matrix is hydrophilic, imbibing water during its daily functions. (See Chapter 1 for more information on collagen fibers.) Annular

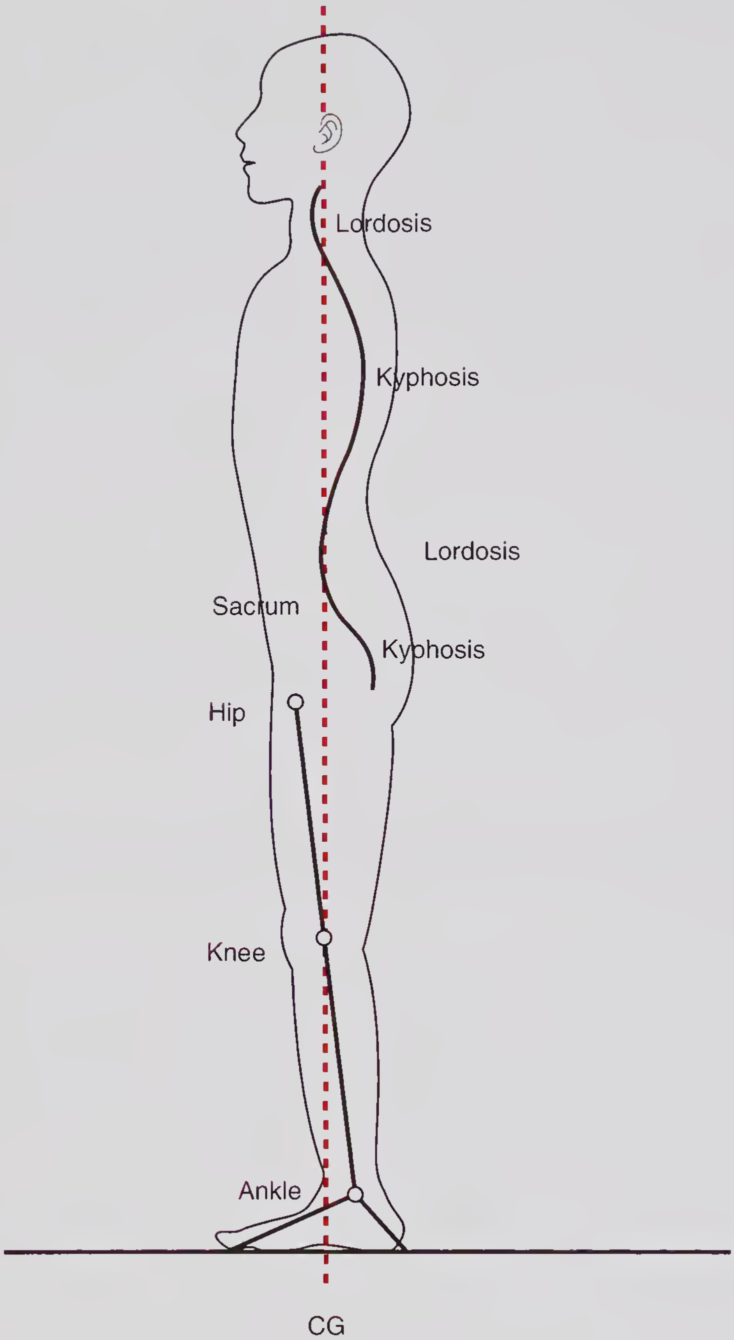


FIGURE 2.1

Posture: Relationship to Center of Gravity All 4 curves of spine (curved line) relate to center of gravity (CG).

collagen fibers are contained in 10 to 20 concentric lamellae, with each fiber crossing at a 65-degree angle to the longitudinal axis of the vertebral column. The angulation differs according to the varying compressive forces. The angle and length of the collagen fibers of the annulus also differ as related to their proximity to the nucleus (Figure 2.8). The angulation and lengths of the annular fibers vary according to the forces imposed on the disk (Figure 2.9).

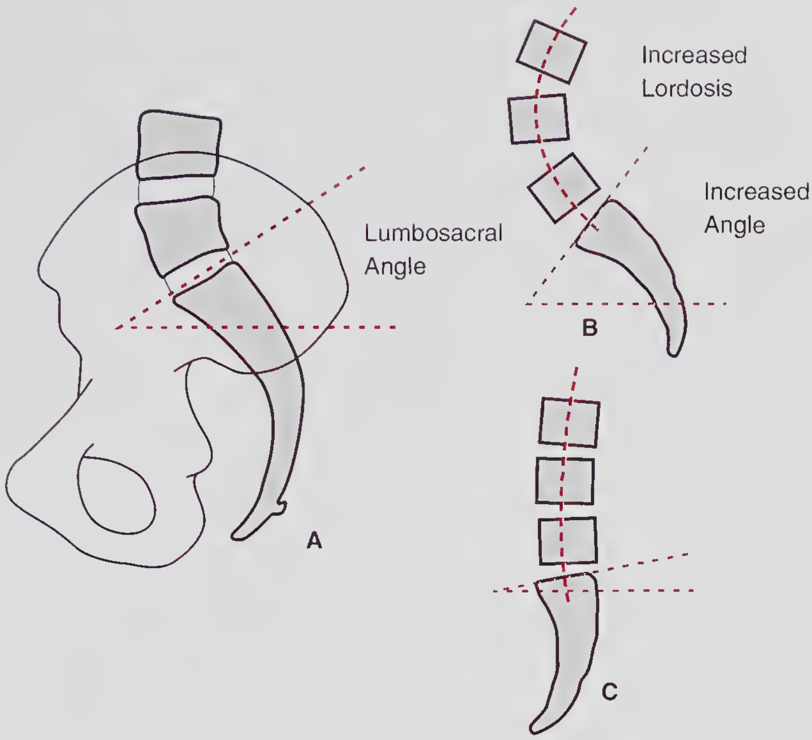


FIGURE 2.2

Lumbosacral Angle A, Normal lumbosacral angle. B, Increase in lumbar lordosis with increase in lumbosacral angle. C, Decrease in lordosis from decrease in angle.

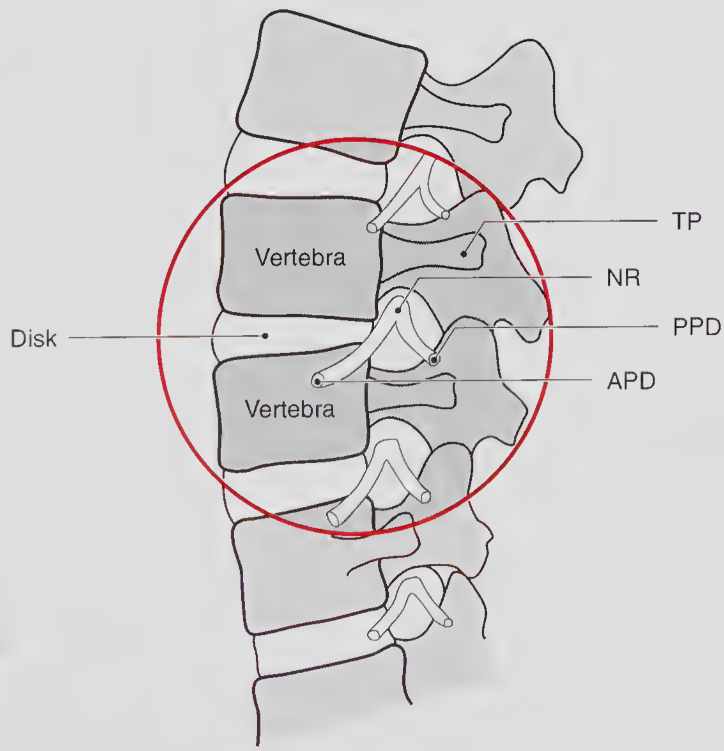


FIGURE 2.3

Functional Unit Adjacent vertebrae separated by disk. TP indicates transverse process; NR, nerve root; PPD, posterior primary division; and APD, anterior primary division.

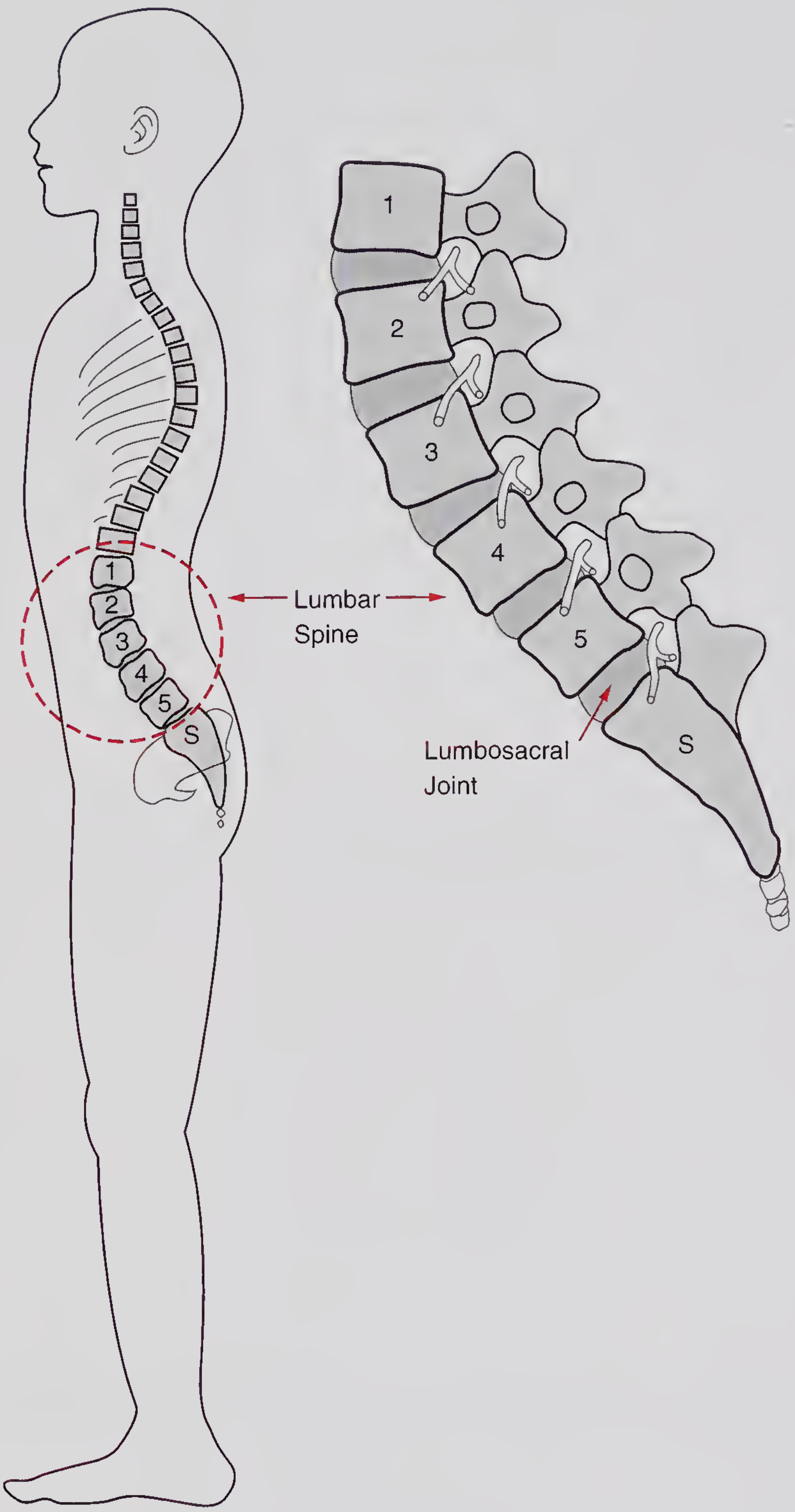


FIGURE 2.4

Lumbosacral Spine The lumbosacral spine usually consists of five functional units. Occasionally some units are fused. S indicates sacrum.

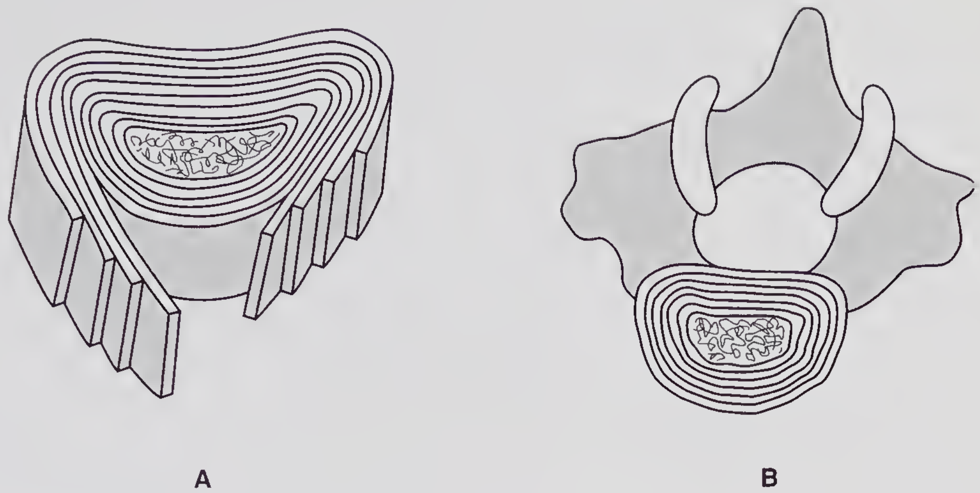


FIGURE 2.5

Intervertebral Disk A, Intervertebral disk consists of centrally placed nucleus surrounded by sheaths of annular fibers. B, Location of disk in vertebral unit.

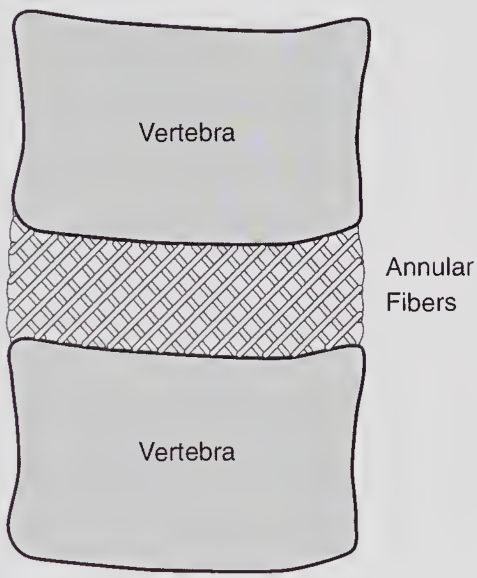


FIGURE 2.6

Annular Fibers Annular fibers surrounding nucleus and in layers have collagen fibers that are oriented at 30 degrees. Each layer goes in opposite direction.

The vertebral end plates to which the collagen fibers of the disk attach are remnants of the growth plates, which are fibrocartilage in young children. The cartilaginous end plate undergoes calcification and ossification in a circumferential manner, forming a ring around the end of each vertebra (Figure 2.10).

The intervertebral disk separates 2 adjacent vertebrae due to its intrinsic internal pressure and causes tension of the annular fibers[5] (Figure 2.11). Hydrodynamic tension occurs within the nucleus but also within the annulus. Removal of the nucleus does not impair compression loading but permits "creep" of adjacent vertebrae.[6]

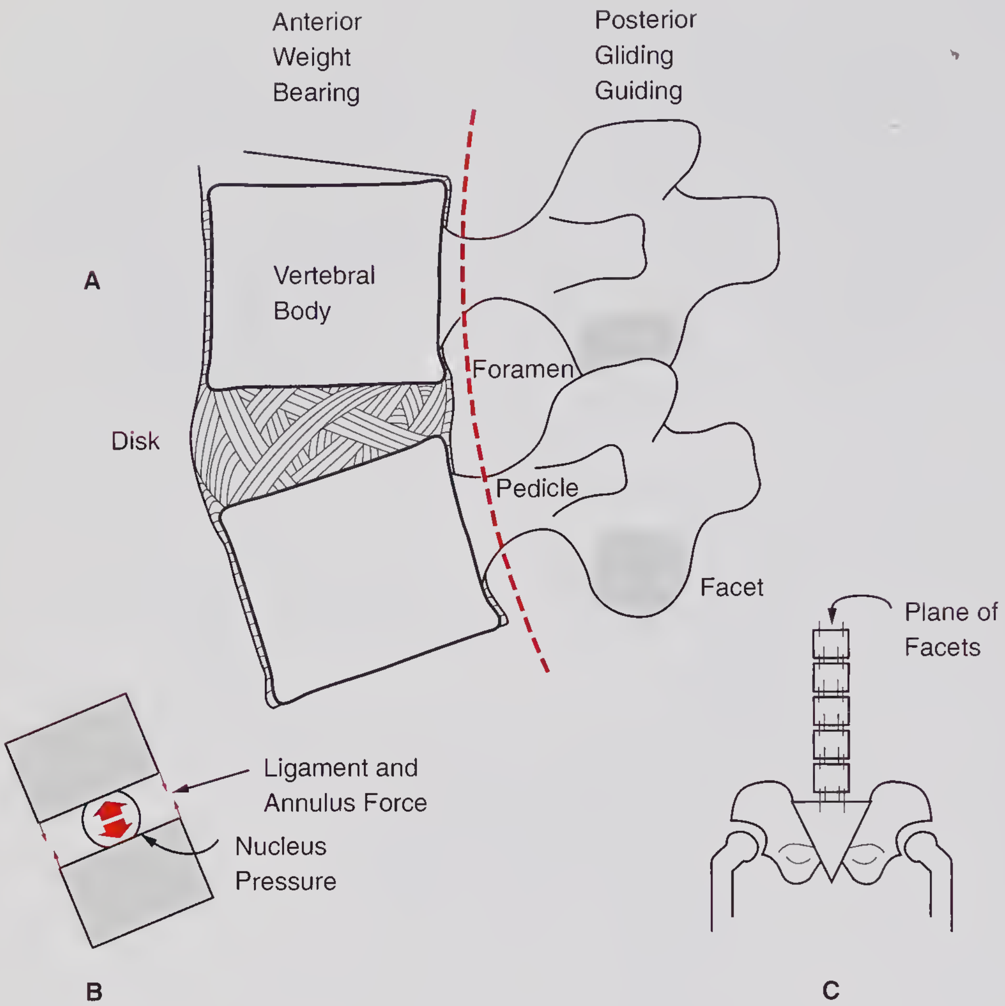


FIGURE 2.7

Intervertebral Disk A, Side view of intervertebral disk shows crisscrossing of annular fibers located in anterior weight-bearing portion of unit. B, Schematic representation of nuclear forces (short, thick arrows) separating vertebral bodies. Thin arrows show longitudinal ligaments and outer annular fibers. C, Sagittal alignment of facets in posterior gliding portion of unit.

The sagittal lumbar curvature has been based and determined from anthromorphic radiologic studies of the human erect posture. Initially, it was measured as Cobb angle (Figure 2.12). This angle was not based on the erect posture and does not reflect the factor of gravity; it depicts a smooth curvature at all segmental levels. More recent studies have clarified the lordosis at each segment, with 65% of cases occurring between L4 and S1[6] (Figures 2.13, 2.14).

Stability of the Lumbar Spine

The spine simultaneously performs both a static and a dynamic function. The anterior portion of the functional unit is considered the "weight-bearing" portion of the unit, and the disk annular fibers with the anterior and posterior longitudinal ligaments afford the stability.[6] In addition, the facets have

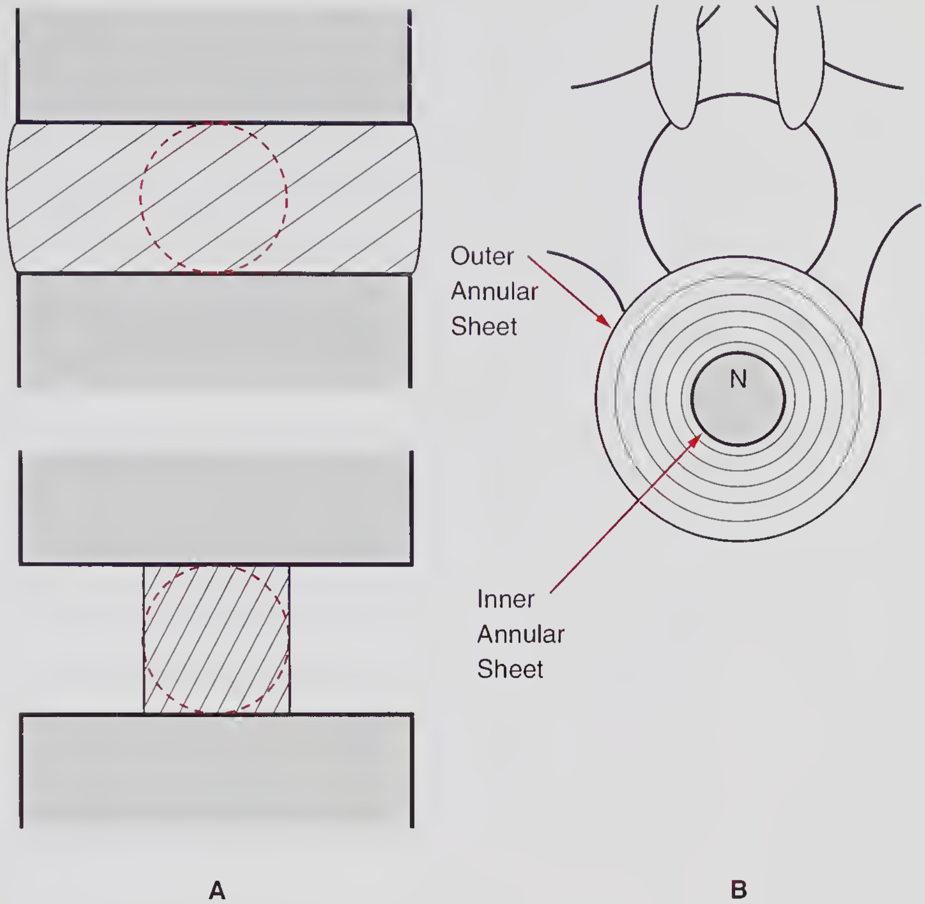


FIGURE 2.8

Variation of Fiber Angulation A, Angulation in outer layers (top) and angulation of fibers next to nucleus (bottom). B, Outer and inner annular sheets shown in A.

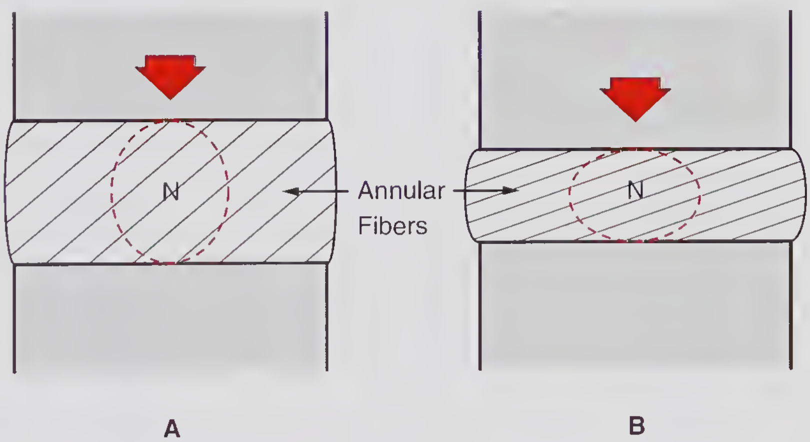


FIGURE 2.9

Annular Fiber Angulation Under Varying Forces A, Annular fiber angulation and length in disk under no pressure. Angle of fibers is at approximately 30 degrees. B, Disk that is elongated changes fiber angle and length, as do compressive forces. During lumbar flexion-extension, angles change, as they do in shear forces. N indicates nucleus; arrows, pressure force.

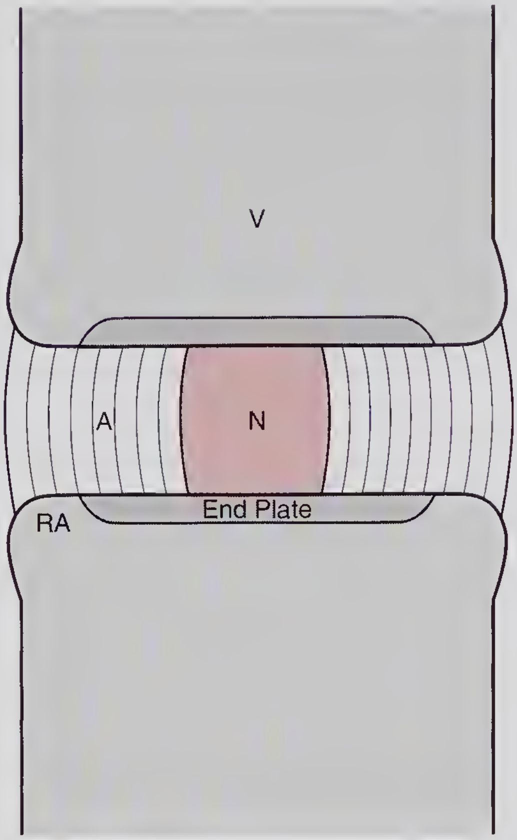


FIGURE 2.10

Vertebral End Plate End plates of vertebral bodies (V) calcify, forming ring apophysis (RA). Disk nucleus (N) is centrally located, and annular fibers (A) attach to ring, with inner fibers attaching to end plate.

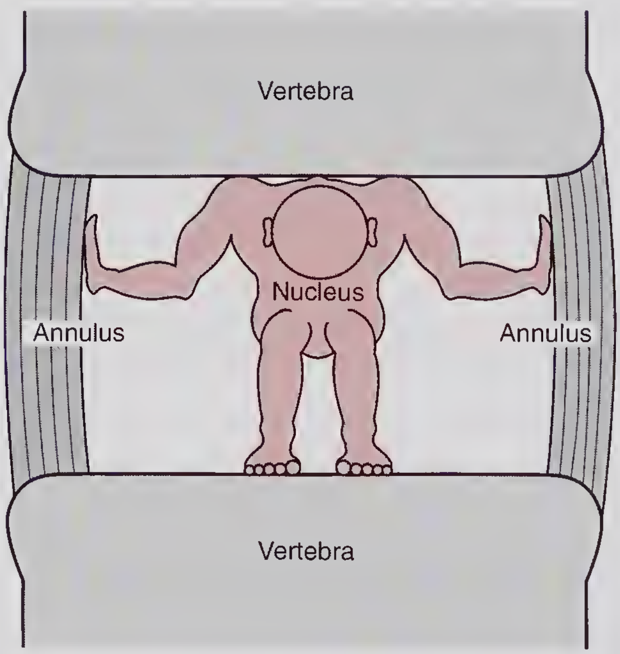


FIGURE 2.11

Function of Disk Nucleus Nucleus pulposus has intrinsic pressure that separates 2 adjacent vertebral end plates and keeps annular fibers taut.

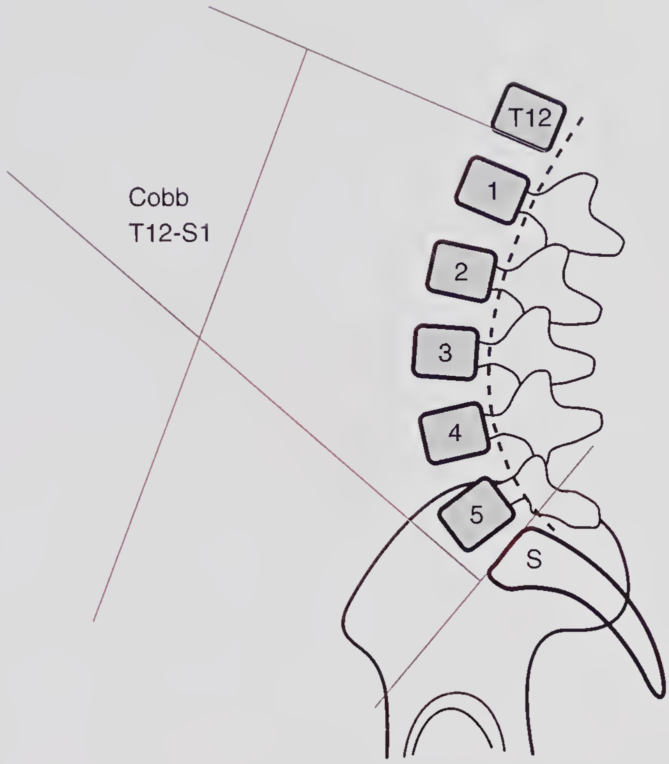


FIGURE 2.12

Cobb Angle Cobb angle was determined as angles based on a line from inferior surface of T12 vertebra and a line drawn from superior surface of sacrum (S).[7]

been accepted as being weight-bearing.[8] The effects of spinal muscles on stability have been difficult to reconcile until recently, when studies have expounded the task of regaining stability of the lumbosacral spine from discogenic disease or spondylolisthesis.[8]

Shear displacement of the superior vertebra on the immediate inferior vertebra occurs from the lordosis of the erect spine at varying levels.[8,9] Shear is prevented or minimized by the "stiffness" of the annular fibers, which is enhanced by the shear and simultaneous compressive forces (Figure 2.15). Stiffness also occurs in the posterior elements when the disk is stiffer or during torque.[9,10] During flexion of the spine the annular fibers increase in stiffness, as do the supraspinous and interspinous ligaments.[11]

Listhesis

The term *listhesis* indicates translational sliding on one body (vertebra) on the next inferior body (vertebra). Translation has been defined as motion of a rigid body in which a straight line in a body always remains parallel to itself. It is a vector quantity that has magnitude as well as direction. Because translation and listhesis are major factors in spinal instability, they merit discussion.

Due to spinal curvature always stressed by gravity, an angled vertebra has a tendency to slide forward on its angled immediate inferior vertebra. The lumbosacral spine of L5 on S1 is an example (Figures 2.16, 2.17, 2.18).

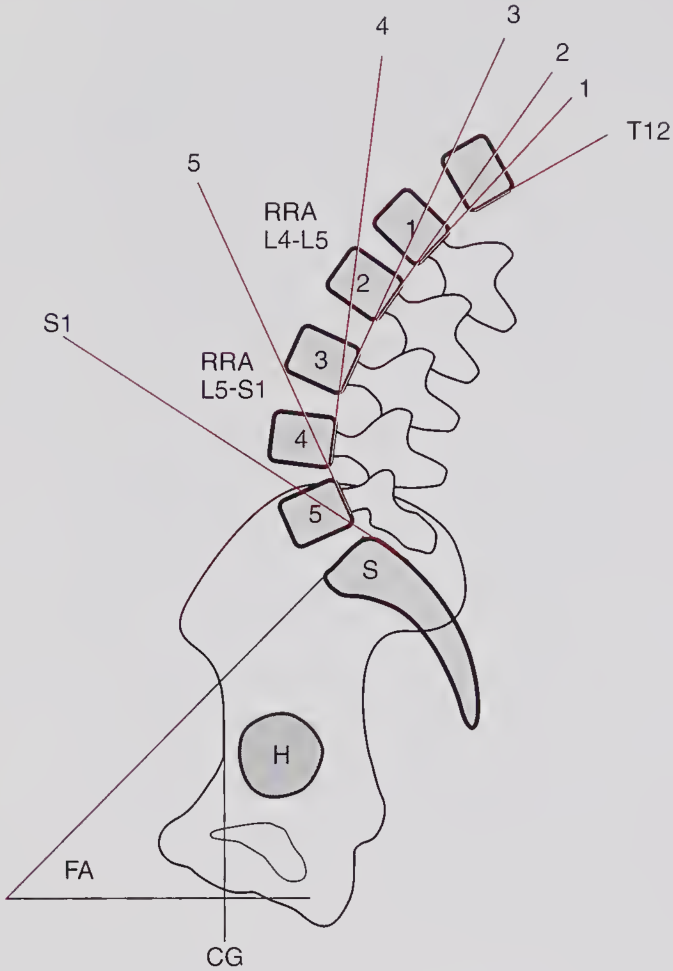


FIGURE 2.13

Elliptical Model of Lumbar Curvature Relative rotational angles (RRAs) with lines drawn from each vertebral posterior surface. RRA L5-S1 and RRA L4-L5 indicate degree of curvature at these 2 levels, which is greater than at other levels. FA indicates Ferguson angle; CG, center of gravity; S, sacrum; and H, hip (femoral head).

Kinetic Spine

As the lumbar spine flexes forward, unless done in a strict sagittal plane, there is simultaneous lateral flexion and rotation. This combined flexion, lateral flexion, and rotation is termed *coupling* and occurs in varying degrees at all segmental levels. In coupling there is also some translation (shear) at each segment by translation (Figures 2.19, 2.20, 2.21).

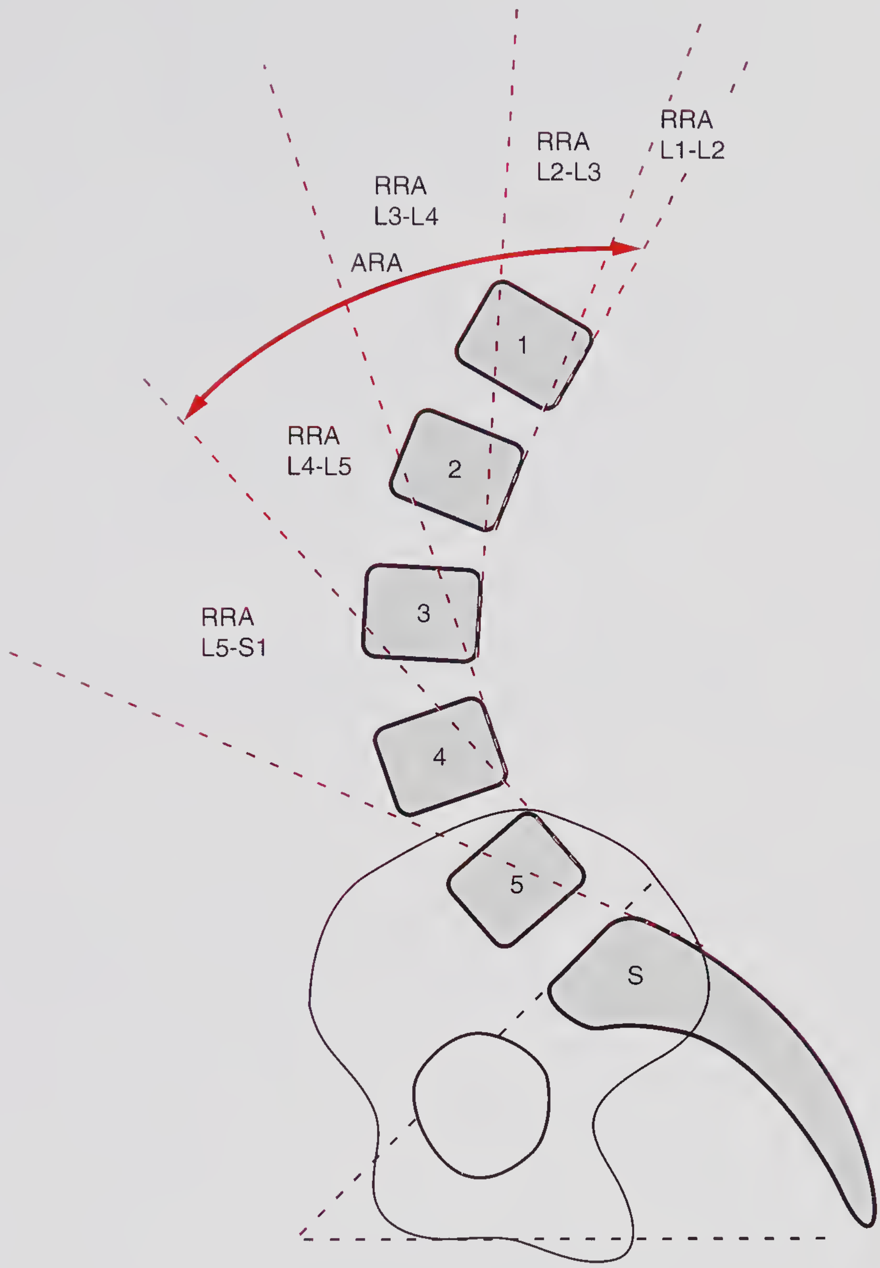


FIGURE 2.14

Relative Rotational Angles at All Levels Each relative rotational angle (RRA) is depicted at each vertebral level of lumbosacral spine. S indicates sacrum.

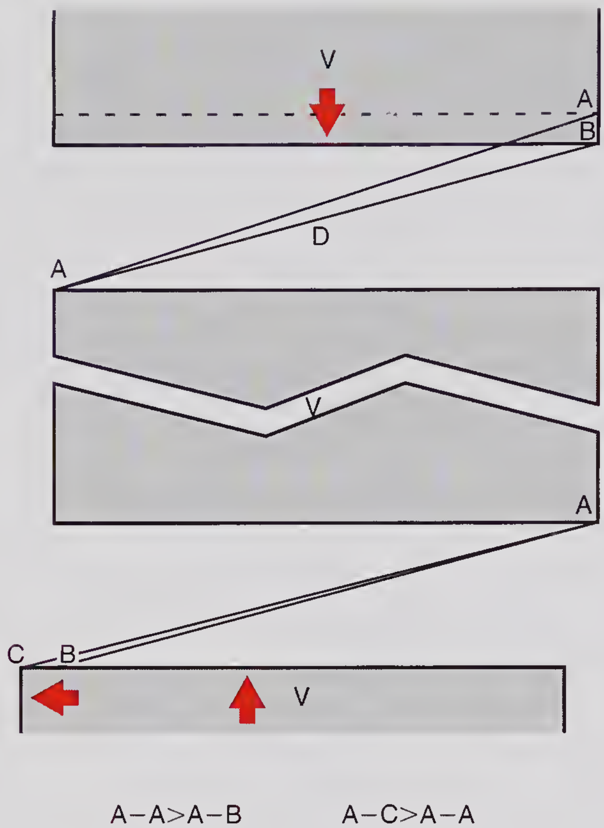


FIGURE 2.15

Collagen Length From Disk Compression and Translation Top figure shows difference in length of collagen fibers (A-A) dependent on width of disk (dotted lines) or when compressed (arrow). A-A is longer than A-B. Figure at bottom shows difference from translation (horizontal arrow). A-C is longer than A-B. V indicates vertebra; D, disk.

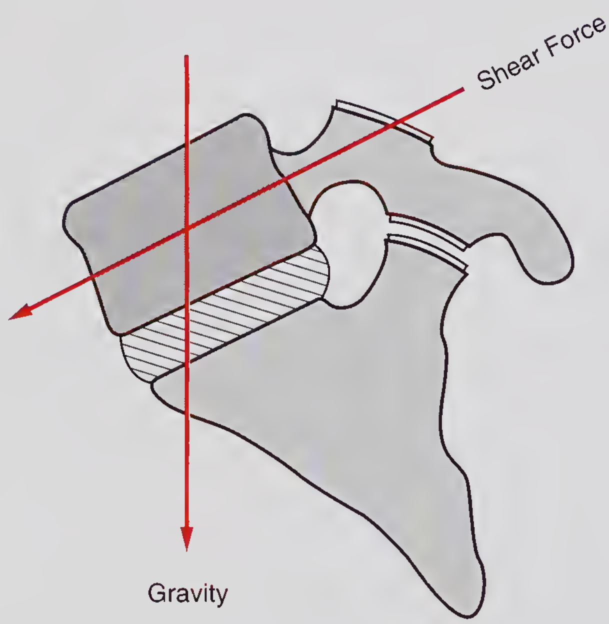


FIGURE 2.16

Angular Relationship of L5 on Sacrum Upper vertebra has shear force in anterior downward direction on sacrum due to gravity.

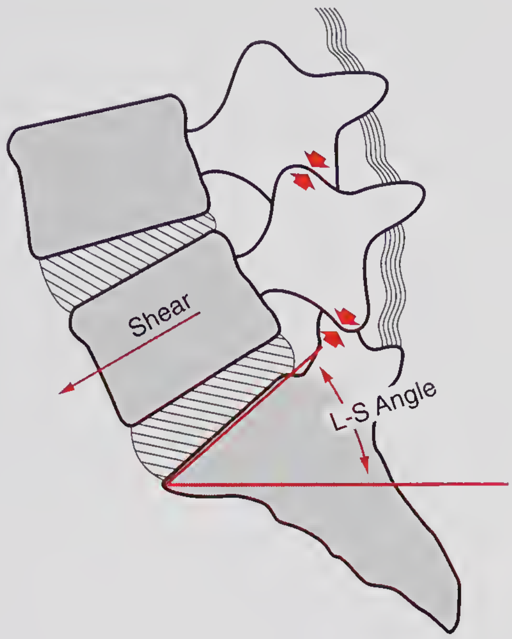


FIGURE 2.17

Resistance of Shear Force of Lumbosacral Spine Lower vertebra experiences downward shear force on sacrum, which is resisted by facets (short, thick arrows).

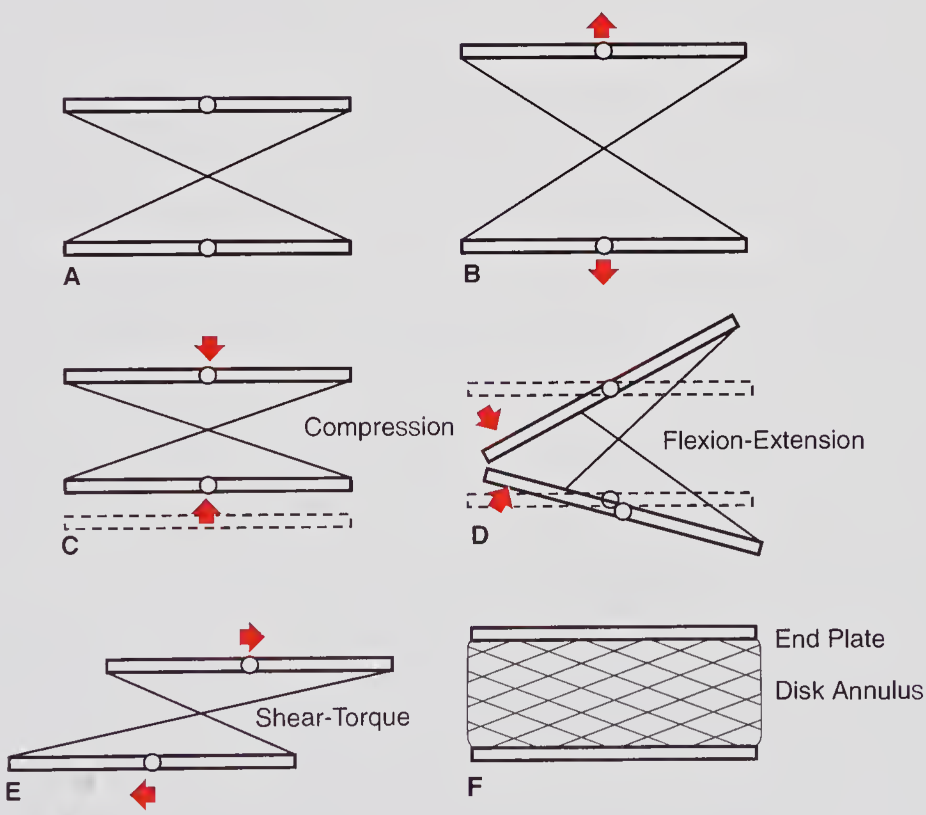


FIGURE 2.18

Intrinsic Changes of Annular Fibers Related to Vertebral Movements A, Angulation of annular fibers in resting normal disk. B, Distraction of disk. C, Compression. D, Normal flexion-extension. E, Shear-torque. F, Normal angulation of fibers. Annular fibers physiologically elongate, as they also change their angulation in normal movements.

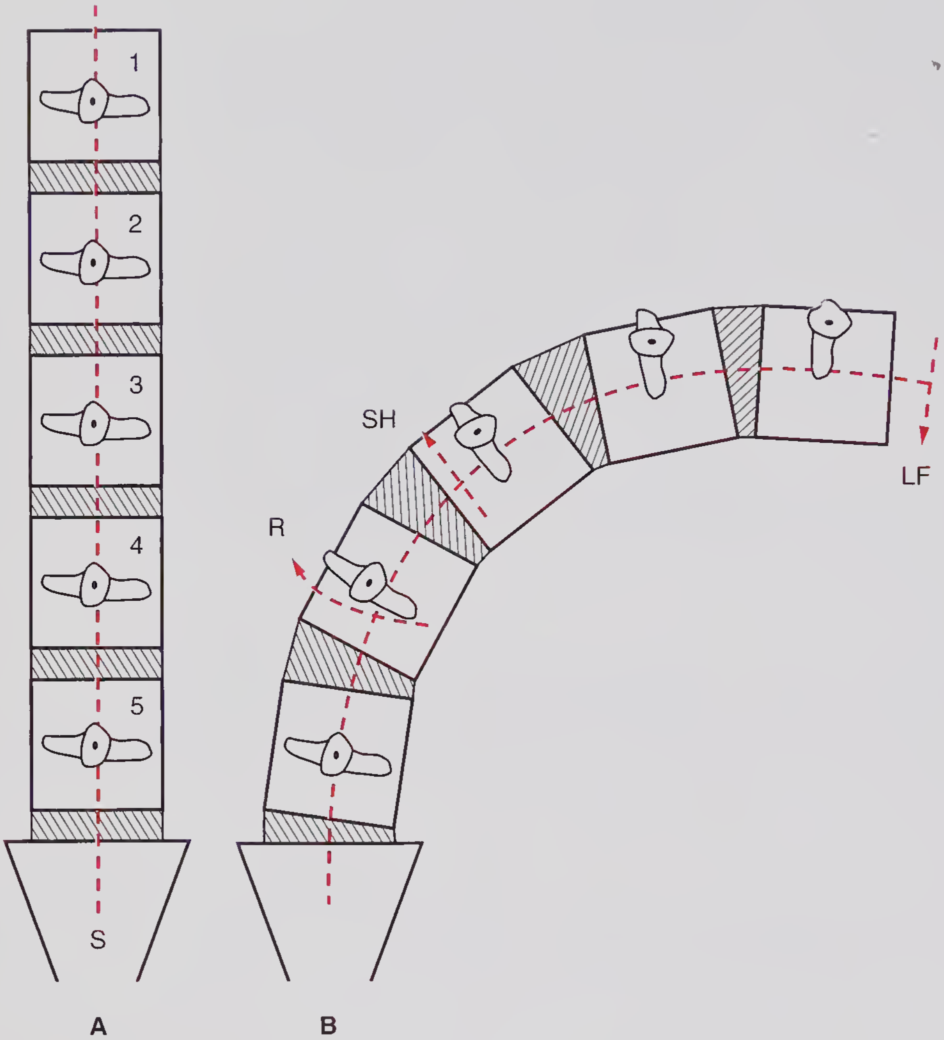


FIGURE 2.19

Spinal Coupling A, Erect spine viewed from rear. All 5 vertebra are in sagittal plane. S indicates sacrum. B, Right lateral flexion (LF) accompanied by rotation (R) toward convex side of flexion. Some shear (SH) is occurring.

In the early 1900s, Lovett[12,13] initially observed a "coupling" motion of the spine in its daily flexion activities and claimed that "lateral flexion probably does not exist in pure movement, but is considered to be one part of a compound movement of the flexing rotating spine" (Figure 2.22).

In numerous studies describing velocity and acceleration of spinal movements, Marras et al[14] propounded the concept of spinal flexion and rotation at numerous angles (Figure 2.23).

In return to the "stable spine" both static and kinetic stability need confirmation and description, as "primary instability" of the lumbar vertebrae was considered to be the most common cause of low back pain.[15,16] Primary instability had been considered to be "listhesis" by Junghanns, which he labeled "pseudolisthesis," as there was no neural arch defect.[17] A diagnosis of listhesis was established by the use of radiologic studies of the

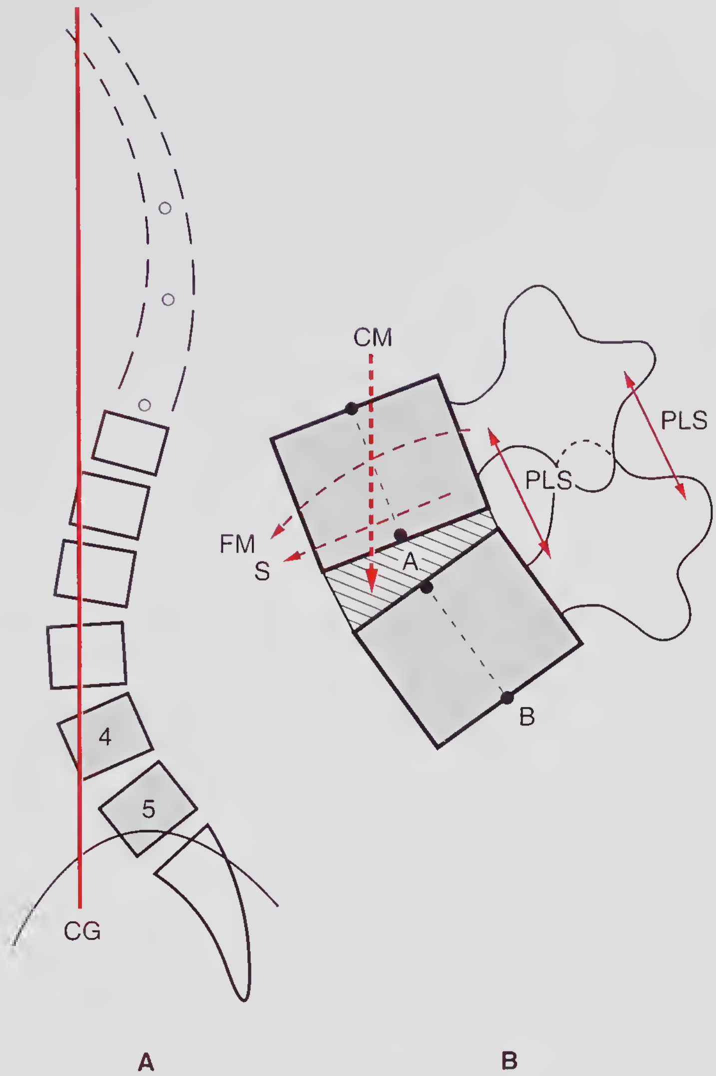


FIGURE 2.20

Flexion-Rotation and Shear at a Functional Unit A, Erect spine with L4 and L5 highlighted as they are angled. CG indicates center of gravity. B, Motion (flexion, FM) of superior vertebra about axis of rotation (A). Flexion is resisted by posterior ligamentous structures (PLS). S indicates shear; CM, compression moment; A-B, angle of vertebra.

spine in full flexion and hyperextension in the upright position.[18] Junghanns established that anteroposterior sliding could be shown long before there was any evidence of disk degeneration. On repeated examinations by numerous investigators, a close relationship was found between lumbar instability and a specific form of disk degeneration caused by trauma. The main abnormalities were splits and clefts between lamellae and incomplete transverse tears in the annulus fibrosus. Secondary instability was used in cases of spondylolisthesis, severe degenerative disk disease, and complete disk herniations or severe protrusion.

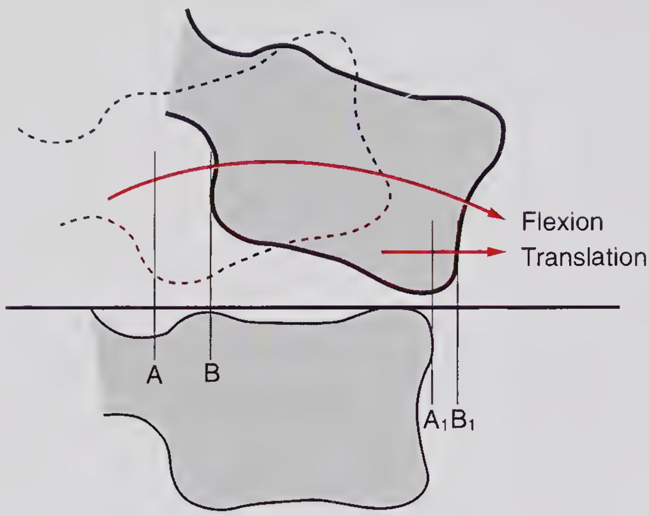


FIGURE 2.21

Flexion and Rotation of Functional Unit Superior vertebra flexes and translates on inferior. Posterior aspect A B indicates range; A_1 B_1, translation anteriorly.

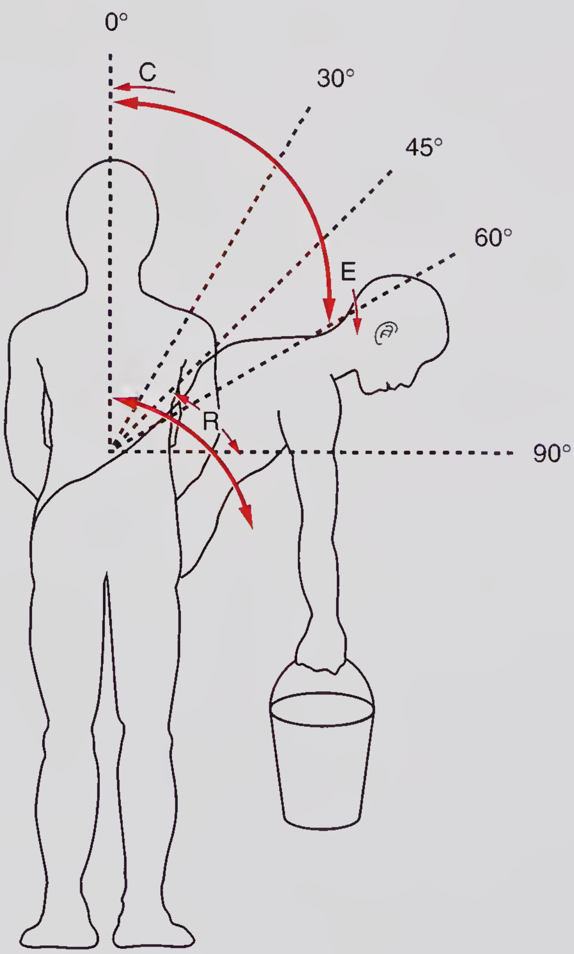


FIGURE 2.22

Flexion-Rotation of Spine Related to Planes of Facets Erect figure shows parallel alignment of facets. Bending figure shows asymmetrical movement of facets. R indicates rotation; E, extension; and C, center of gravity.

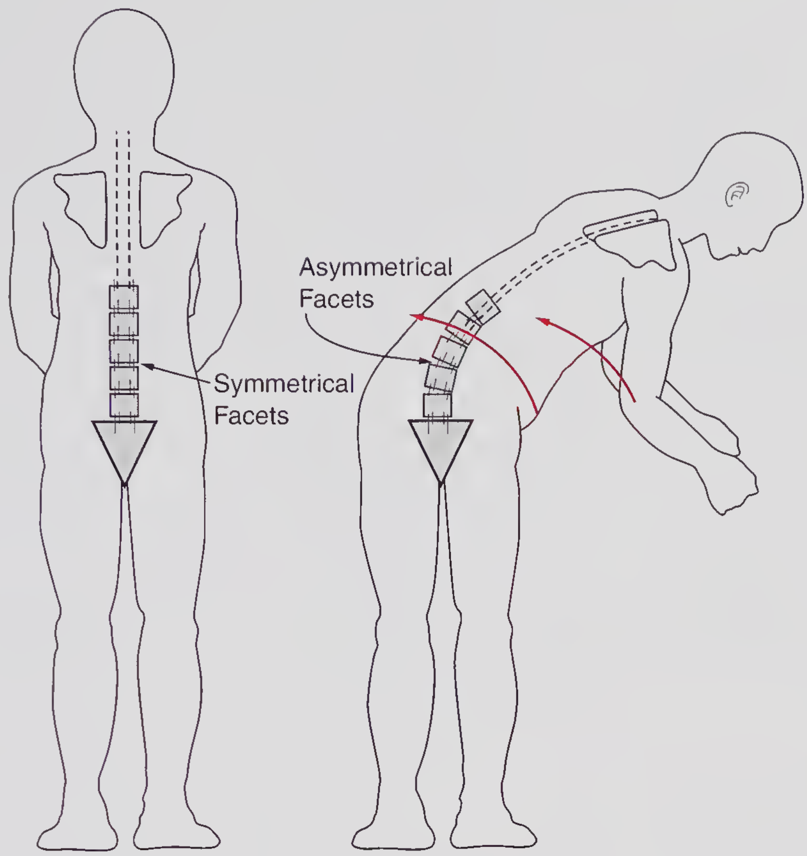


FIGURE 2.23

Asymmetrical Planes Defining Trunk Motion Asymmetrical planes of motion vary from 0 degrees in sagittal plane with 15-degree variants to left and to right.

POSTERIOR SPINAL ELEMENTS

The anterior weight-bearing portion of the functional unit has been discussed, but posterior to the vertebral bodies are the bony elements that form the spinal canal and the lamina, which contain the facets (zygapophyseal joints; Figure 2.24). The facets are paired synovial joints whose articulation is the superior facets of the inferior vertebra and the inferior facets of the superior vertebra (Figure 2.25). By their vertical alignment, they allow flexion-extension and restrict lateral flexion and rotation[17] (Figure 2.26). Their role is also to increase annular torsional rigidity.[19] They also prevent listhesis (Figure 2.27).

In trunk flexion-reextension the facets undergo flexion and extension as well as some rotation and lateral flexion, but they restrict the degree of all motions (Figures 2.28, 2.29, 2.30).

Each plane of facets is enclosed in a redundant capsule, which is anteriorly enforced by the ligamentum flavum of the spinal canal. Small fat pads in each capsule form a meniscus-like structure (Figure 2.31). These "menisci" and capsules are well innervated by proprioceptive nerve endings and nociceptor fibers, so they transmit pain as well as proprioception.[19]

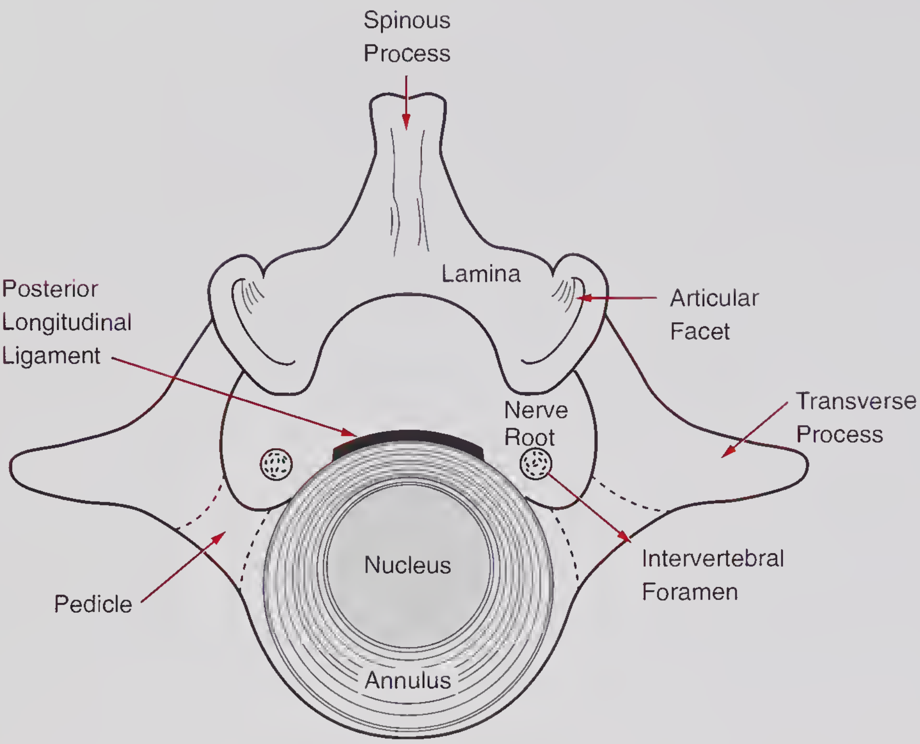


FIGURE 2.24

Functional Unit Various components of spinal functional unit, viewed from above.

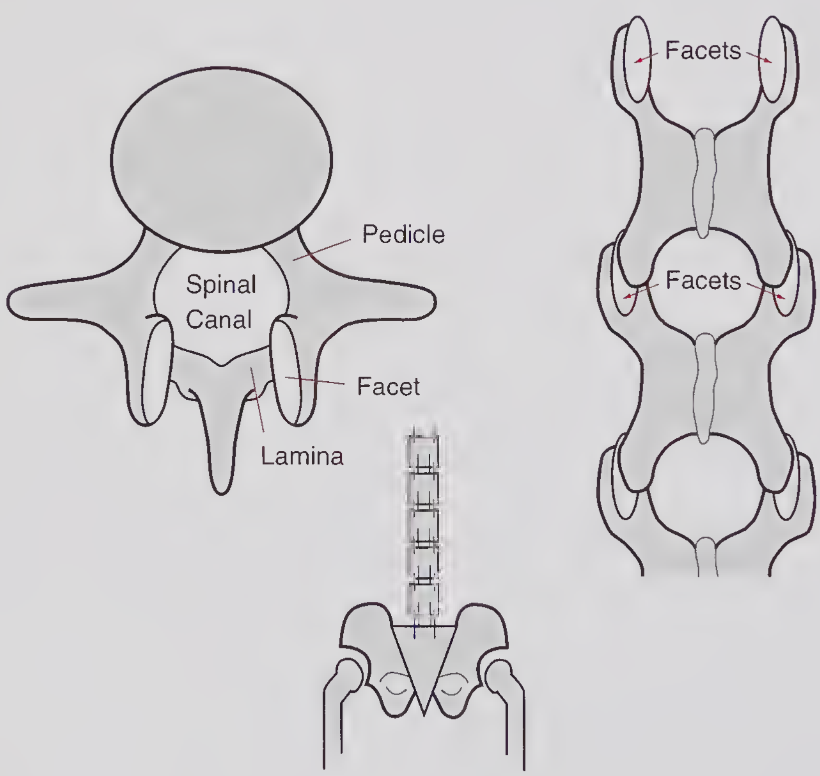


FIGURE 2.25

Facet Alignment Top and rear views (top left and right figures, respectively) depict vertical alignment of facets schematically shown in bottom figure. This facet alignment allows flexion-extension of each functional unit and limits lateral and rotator movement.

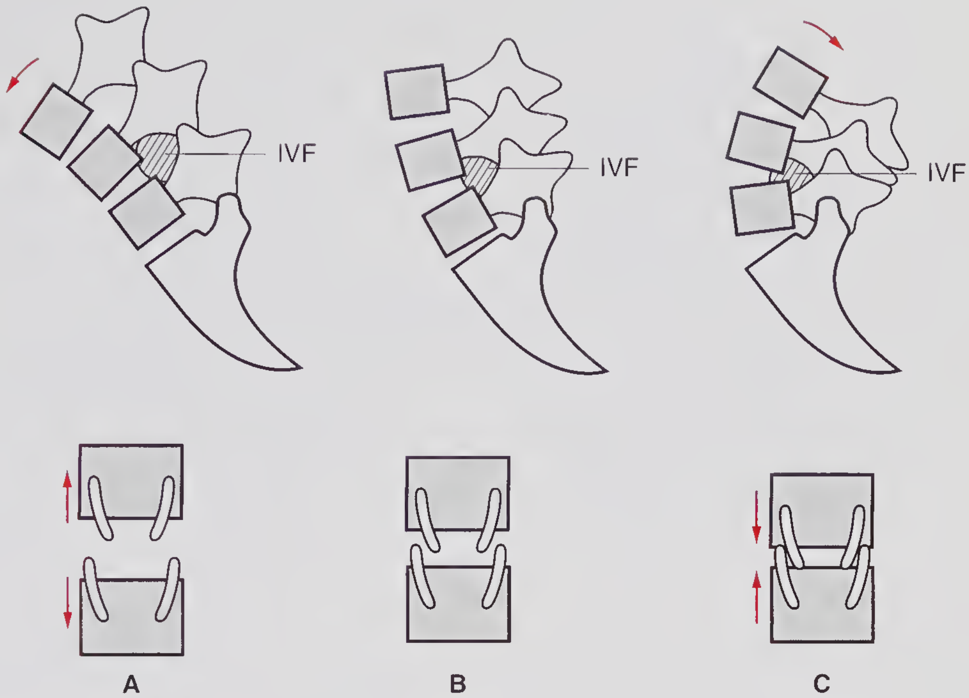


FIGURE 2.26

Facet Movement in Flexion and Extension Central figures (B) show neutral physiological lordosis with facets apart and foramina (IVF) open. Lumbar flexion (A) opens foramina and separates facets. Extension (C) narrows foramina and approximates facets.

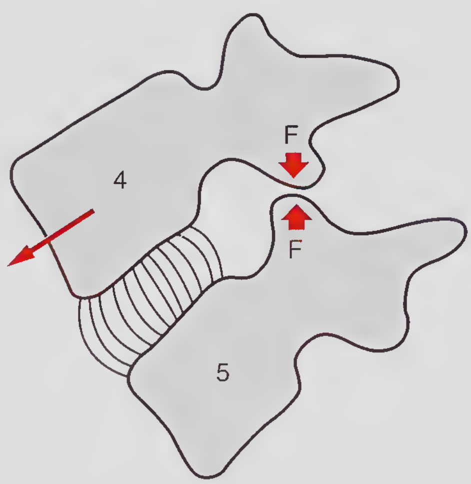


FIGURE 2.27

Shear Stress on Facets Facets (F, dark arrows) (zygapophyseal) joints restrict forward translation (long arrow) of superior facets (4) on inferior facets (5).

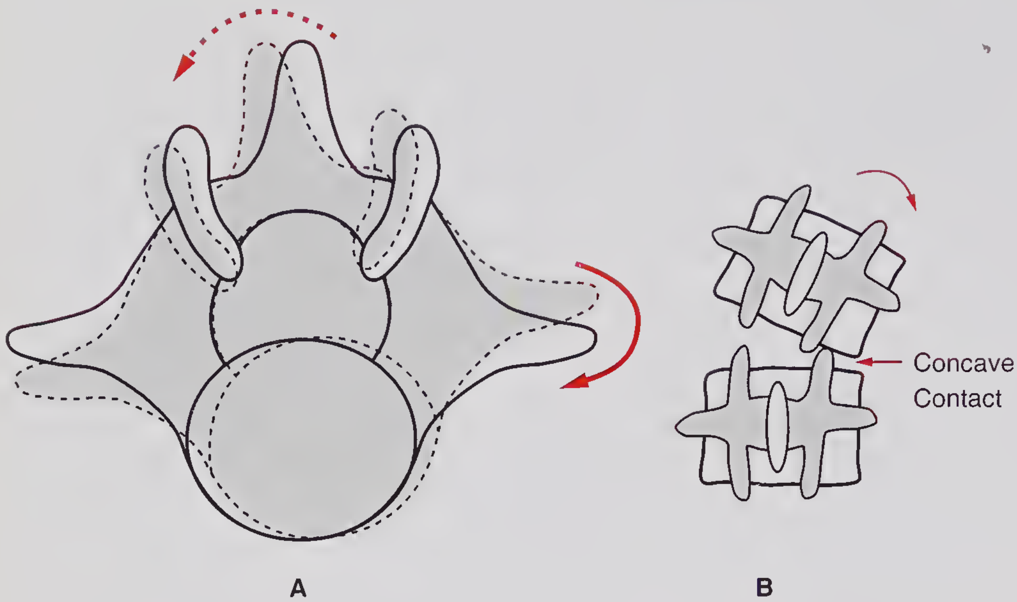


FIGURE 2.28

Lateral Flexion Rotational Torque When a person bends laterally (dotted lines), facets on concave side (A) approximate and become axis of rotation. Facets on convex side (B) separate. Rotation (curved arrow) causes lateral shearing.

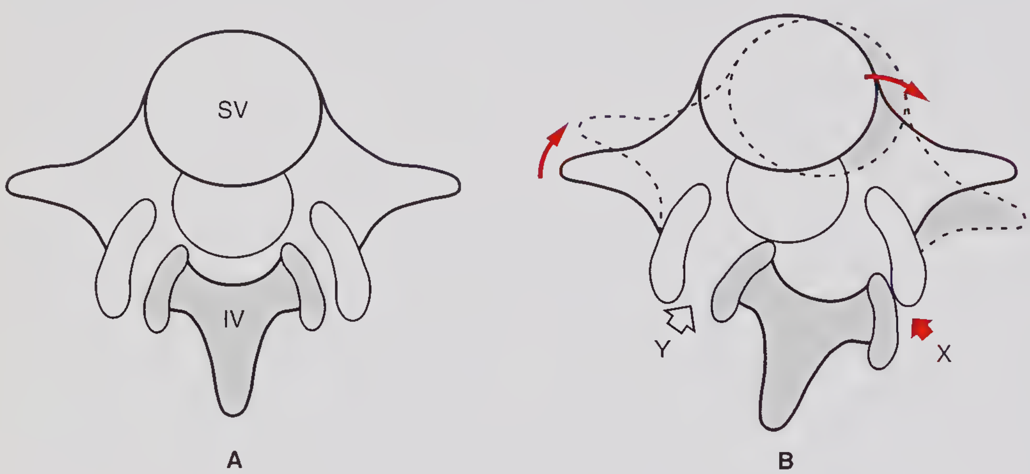


FIGURE 2.29

Axial Rotational of Functional Unit A, Normal alignment of inferior facets (IV) to superior vertebra (SV). B, Rotation around new axis (X), where facets impinged and separated (Y).

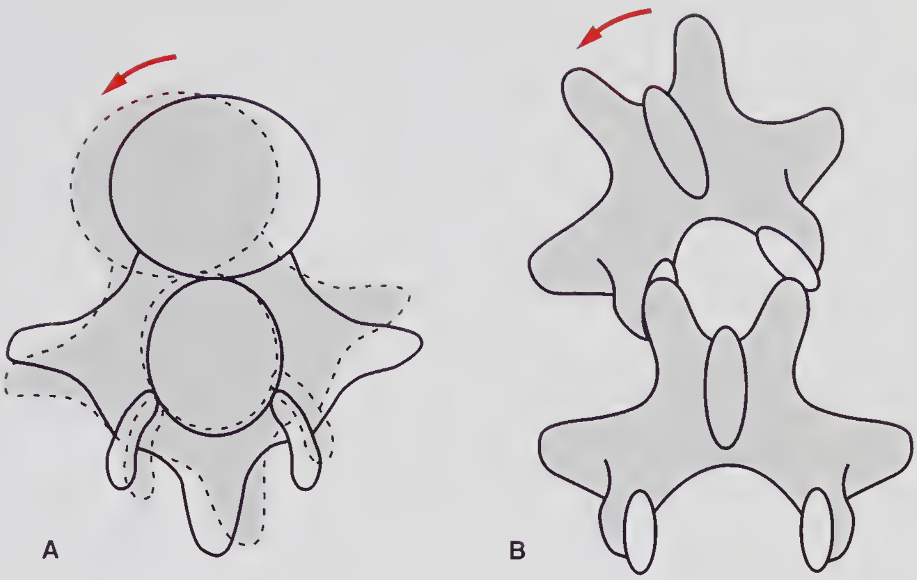


FIGURE 2.30

Rotational Limitation by Facets A, Rotation of superior vertebra (shaded) on the inferior vertebra (clear). B, Facets contact on concave side and limit further motion.

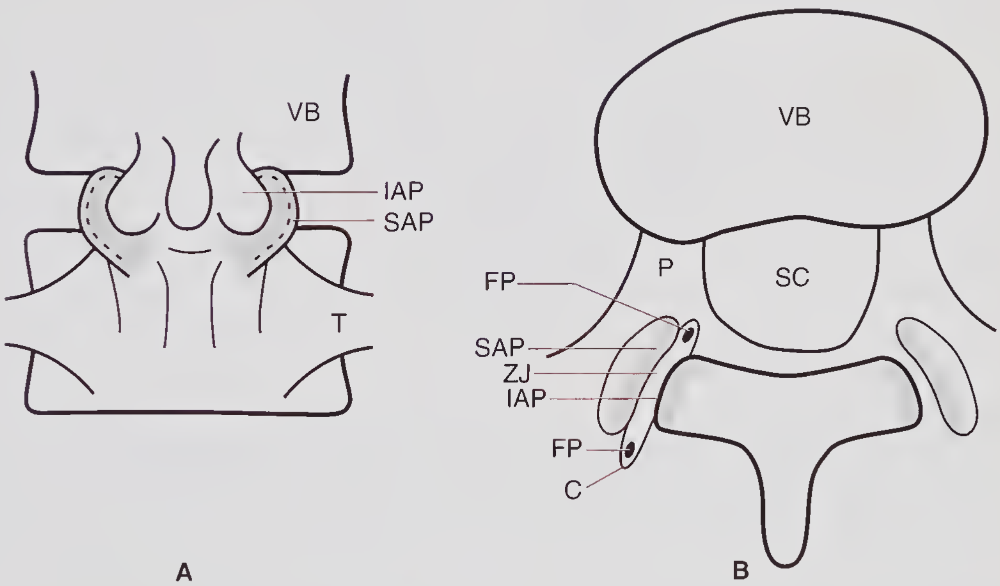


FIGURE 2.31

Zygapophyseal Joints (Facets) Posterior (A) and superior (B) views of functional unit. IAP indicates inferior articular process; SAP, superior articular process; VB, vertebral body; T, transverse process; SC, spinal canal; FP, fat pad; ZJ, zygapophyseal joint; C, capsule; and P, pedicle.

ROLE OF MUSCLES IN THE ACTIVATED SPINE

When the spine is activated to perform an intended task, there is a neurologic sequence of activation of extrafusal muscle fibers of the muscle system, which are monitored by the intrafusal muscle system (Figure 2.32).

Flexion is initiated by contraction of the abdominal flexors with simultaneous co-contraction of the erector muscles of the spine as they decelerate

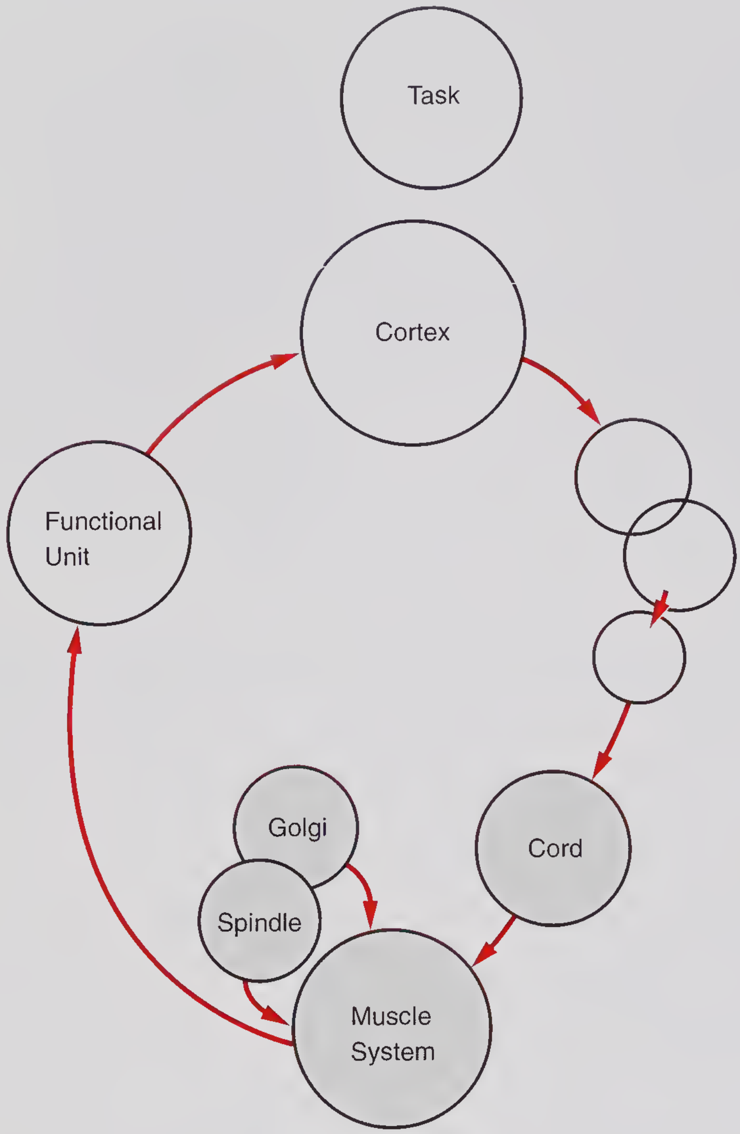


FIGURE 2.32

Sequence of Neuromuscular System In the sequence from cortex through midbrain and then spinal cord, ultimate contraction of extrafusal muscle fibers monitored by intrafusal system initiates desired action.

trunk flexion. The configuration, direction, and angulation of the muscle fibrils have been well documented by Bogduk et al[1] and Macintosh et al[1] (Figure 2.33).

In erect posture, the angulation of the fibrils varies according to the degree of lordosis and the distance from the axis of rotation. In trunk flexion, the alignment changes with each degree of angulation of each functional unit as the spine progressively flexes (Figures 2.34, 2.35).

The multifidus and the iliocostal-longissimus muscles crisscross during flexion. Their alignments vary, but their torque or compressive forces do not change.[20] In erect posture, the fascicles of the multifidus are oriented in a dorsocaudal position but become ventrocaudal in flexion, whereas the fascicles of the longissimus merely align more to the longitudinal axis of

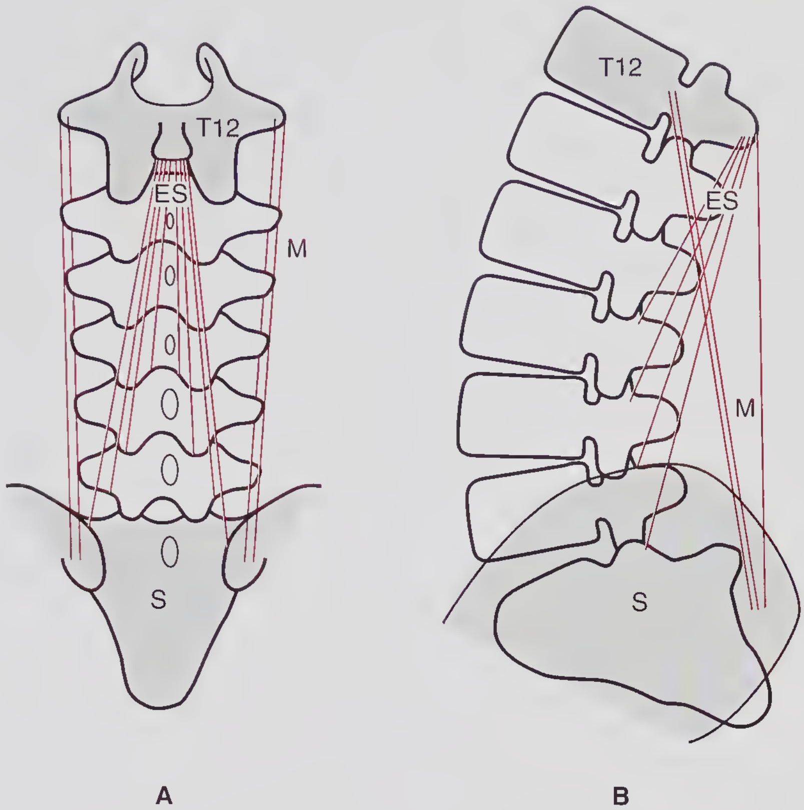


FIGURE 2.33

Attachments of Erector Spinal and Multifidus Muscles A, Posteroanterior view of extensor muscles of spine (ES) and multifidus muscles (M) and their attachments. S indicates sacrum. B, Lateral view of angulation of these muscles as they attach to 12th thoracic vertebra and from sacrum (S) and posterior processes of ilia. (Adapted with permission from Bogduk et al.[1])

the spine (Figure 2.36). The quadratus lumborum is a sagittal muscle that originates and inserts from the 12th rib, the iliac crest, and the transverse processes (Figure 2.37). The deep intersegmental muscles also help stabilize the spine (Figure 2.38).

Most bending (flexing) and lifting activities are 3-dimensional: forward flexion, lateral flexion, and rotation.[21,22] They demand a complex coordination of a large number of trunk muscle forces.[22-25] These are "agonist" muscles that move about a moment arm of L4 and L5. They are the external and internal oblique muscles, erector muscles of the lumbar spine, rectus abdominis, and latissimus dorsi.

Along with agonist contraction, there is also a simultaneous contraction of the antagonists. This co-contraction is needed to equilibrate movements causing stiffness, stabilization, and compressive forces of the passive tissues.[4] Compressive forces contribute to spinal stiffness.[26] Co-contraction with the antagonists probably protect the joint against injury from large abrupt forces of the agonists, as it has been shown that the stability of the human lumbar spine is diminished during periods of low muscular activity.[21,27-29]

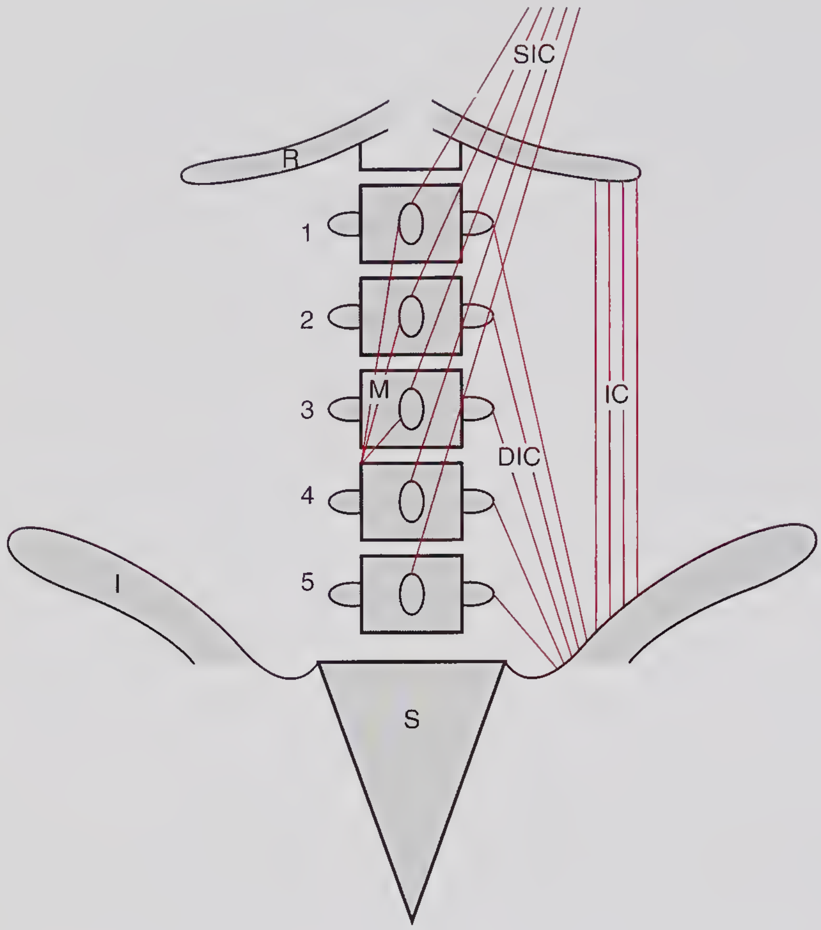


FIGURE 2.34

Trunk Musculature Fibers of iliocostal (IC), superficial iliocostal (SIC), and deep iliocostal (DIC) muscles go in different directions; thus, they place different forces on vertebrae of lumbar spine yet are similarly innervated. Multifidus muscles (M) are also shown. I indicates os ilium; S, sacrum; and R, ribs.

The superficial muscles are recruited first to balance the external loads, whereas the deeper segmental muscle close to the center of rotation is in a better biomechanical position to increase stability of the functional units.[28]

Neural feedback subsystems regulate spinal stability.[14] Fatigue of the agonist due to prolonged submaximal isometric contraction causes a loss of coordination with an increase of co-contraction; thus, an increase in compressive forces as well as increasing stiffness and stability also may damage the disks.[11]

Deceleration forces to trunk flexion have been postulated since the studies of Floyd and Silver,[30] with diminution of myoelectric activity, as occurs during the latter part of trunk flexion. This diminution of antagonists was termed *flexion relaxation* and was assumed to be a reflex activity from impulses sent to the spinal cord from receptors in the stretched ligaments of the posterior elements of the spine (Figure 2.39). The facet (zygapophyseal joint) capsules also become stretched at the end of flexion and are known to contain proprioceptors that provide resistance to vertebral flexion. In addition, stretching of the facet capsules produce inhibitory responses in the lumbar paraspinal musculature. During the electrically

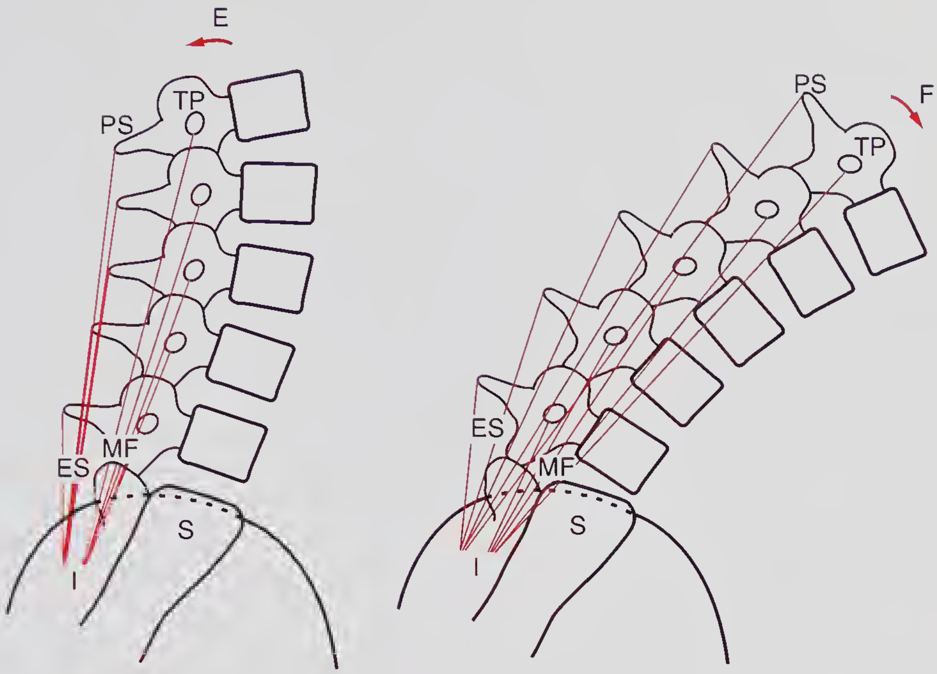


FIGURE 2.35

Extensor Muscles in Trunk Flexion-Reextension In erect posture (E), erector muscles of spine (ES) and multifidus muscles (MF) generate specific force and have a specific length and angulation. Erector muscles of spine attach to posterior spinous processes (PS), and multifidus muscles attach to transverse processes (TP). In flexed trunk position (F), erector spinal (ES) and multifidus (MF) muscles elongate and generate less force, but this is balanced by elastic increase in elongated muscles. These forces are both eccentric and concentric. I indicates iliac crest; S, sacrum.

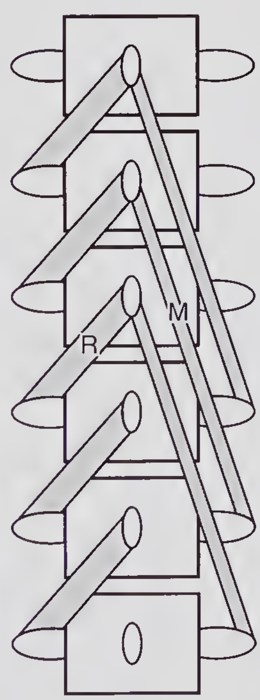


FIGURE 2.36

Stabilizing Muscles Small proximal muscles that stabilize spine are rotators (R) and multifidus (M).

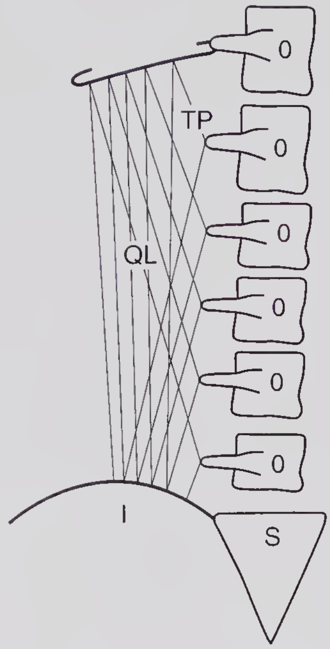


FIGURE 2.37

Quadrate Muscle Musculus quadratus lumborum (QL) attaches from iliac crest (I) to transverse processes (TP) of lumbar spine and 12th rib. S indicates sacrum.

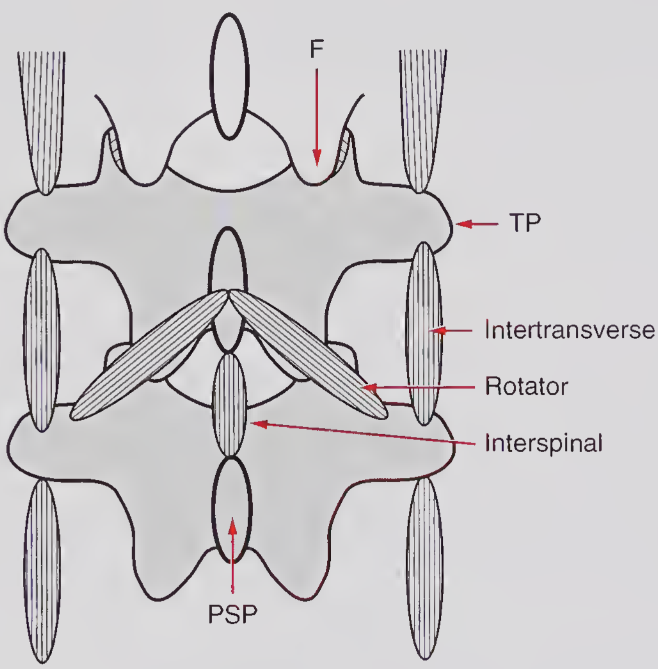


FIGURE 2.38

Deep Intersegmental Muscles Deep intersegmental muscles are extensors, lateral flexors, and rotators. Their attachments are on transverse processes (TP) and posterior spinous processes (PSP). Facets (F) are shown.

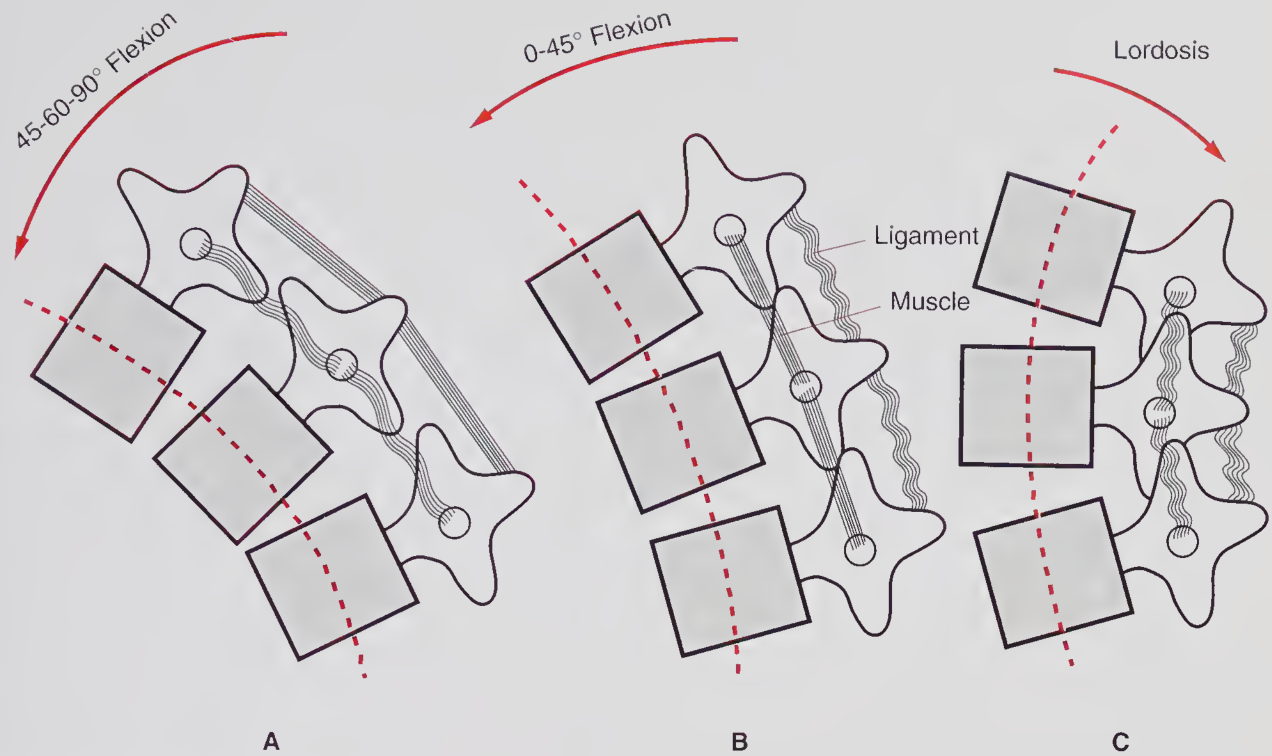


FIGURE 2.39

Restraint of Flexion of Lumbar Spine A, Within last 15 degrees of flexion, extensor muscles become "silent," and restraint occurs from posterior ligaments and fascial tissues. B, First 45 degrees of trunk flexion, with extensor muscles contracting eccentrically to allow flexion. C, Spine in hyperextension when soft tissues are quiet.

"silent" phase, resistance is provided by the deep lateral muscles (quadratus lumborum and iliocostal), which have become active. The superficial muscles (multifidus) become silent.

This neuromuscular coordination will become apparent when patients with chronic low back pain present with loss of flexion relaxation, which predisposes them to injury and pain.[30,31] They have limited trunk flexion-extension and rotation due to persistent activity of the musculature, which now acts as stabilizers rather than mobilizers. There is a discrepancy in spinal leverage to be considered in understanding spinal mechanics[32] (Figure 2.40).

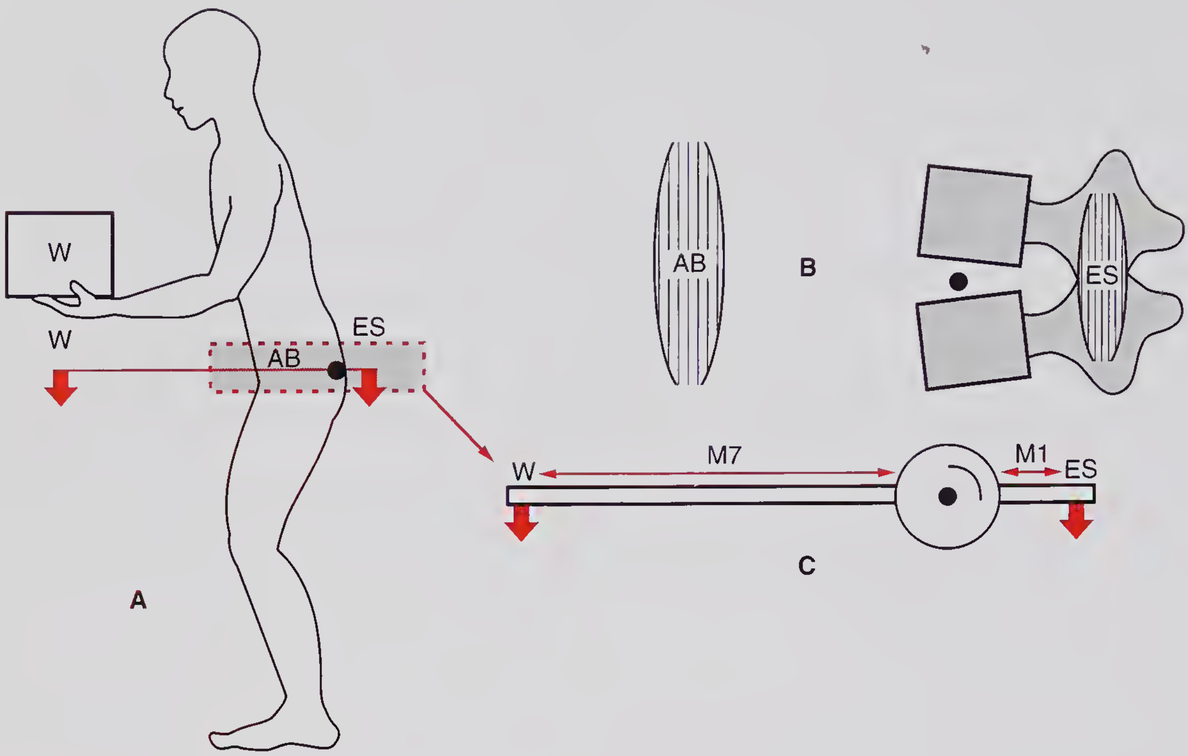


FIGURE 2.40

Discrepancy of Spinal Leverage A, Person holding object (W) at a distance from the body. Distance M7 has leverage (C) from axis of rotation (circle with central dot) balanced by erector muscles of spine (MS) at much smaller distance (M1). B, Muscles involved are abdominal (AB) and extensor muscles of spine (MS).

LUMBOSACRAL RHYTHM

The erect spine finds the spinal muscles essentially "silent" except for exhibiting tone. As flexion begins, the abdominal muscles contract with appropriate force and speed depending on the task intended. The extensor (antagonistic) muscles appropriately contract eccentrically, as determined by the spindle Golgi apparatuses.

In the lumbar pelvic rhythm, the pelvis remains reasonably static while the lumbar spine begins flexion (Figure 2.41). Flexion occurs at each functional unit with a flexion movement and some shear when total trunk flexion is contemplated. Full flexion restraint is also assisted by the myofascial restraint (Figure 2.42).

In the role of reextending to the erect posture with the lumbar spine resuming its lordosis, the fascia exerts force with sporadic muscular components. The pelvis also derotates to its neutral position (Figure 2.43).

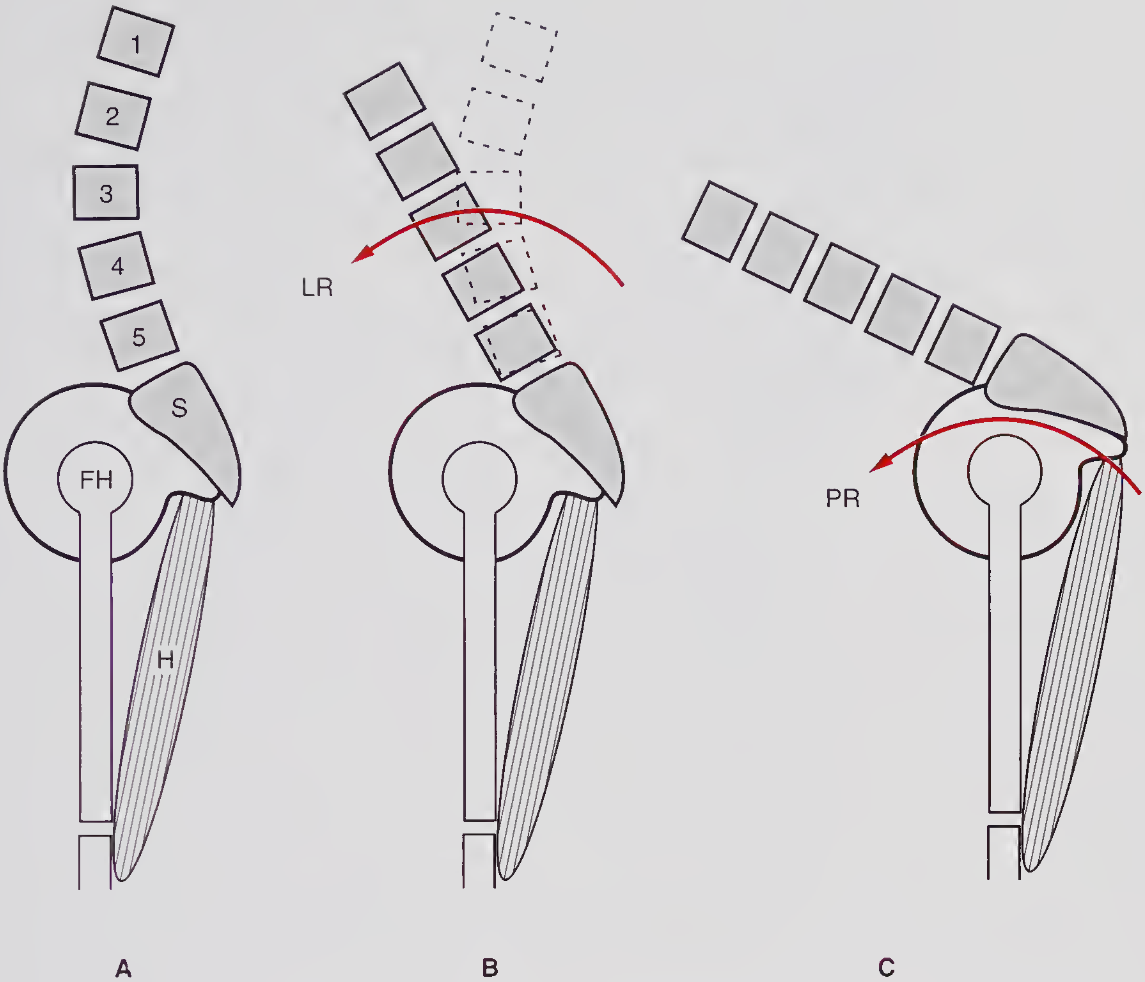


FIGURE 2.41

Lumbar-Pelvic Rhythm A, Erect spine with lumbar lordosis and pelvis remaining neutral (no rotation). S indicates sacrum; FH, femoral head; and H, hamstring muscles. B, Lumbar flexion (LR) with the pelvis remaining neutral (no rotation), held there by isometric contraction of hamstring and gluteal muscles. C, Further spine flexion with lumbar spine fully flexed in almost straight position and all motion occurring at pelvis (PR).

When there is contraction of the abdominal muscles to initiate flexion, the muscles of the pelvis, which remain static, contract isometrically. This complex neural pattern is engrained in the central nervous system at all levels. In the descent phase of bending, the erector muscles of the spine contract "eccentrically" as they elongate. When the muscles have fully elongated, the fascial tissues and ligament become the "mobilizer" forces. After full flexion and when there is active reextension, the pelvis muscles and the fascial tissues of the lumbar spine become the mobilizers (Figure 2.44).

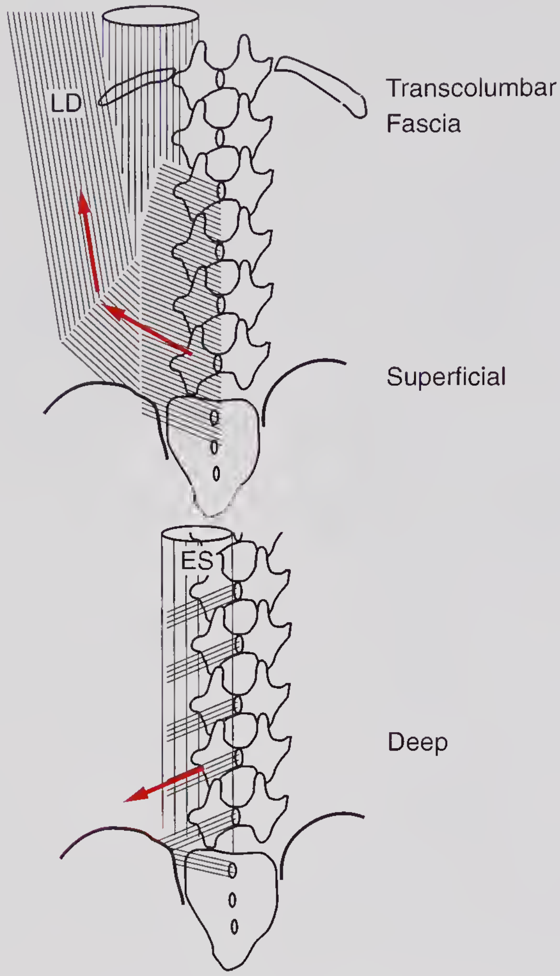


FIGURE 2.42

Thoracolumbar Fascia Muscle can elongate to extent that its fascial sheath permits. Extrafusal muscle fibers elongate eccentrically, but fascia elongates passively and shortens when muscle contracts. ES indicates erector muscles of spine; LD, latissimus dorsi muscles.

LIGAMENTS IN SPINAL FUNCTION

The ligaments of a functional unit—anterior longitudinal, posterior longitudinal, flaval (ligamentum flavum), intervertebral, and posterior supraspinous ligaments—contribute very little, if anything, toward maintaining spinal stability. During "creep" of 2 adjacent vertebrae, the loss of forces in the ligaments is not considered to be a major factor in the creep.[33]

Spinal Instability

The definition of spinal instability has been a subject of considerable concern to the medical profession and has yet to be clearly defined. Any definition implies that motion within the functional unit—two adjacent vertebra separated by a disk, the ligaments, and facet joints—must not exceed normal movement under physiological load levels. Damage to any of these unit components can result in instability. The osteoligamentous spine devoid of

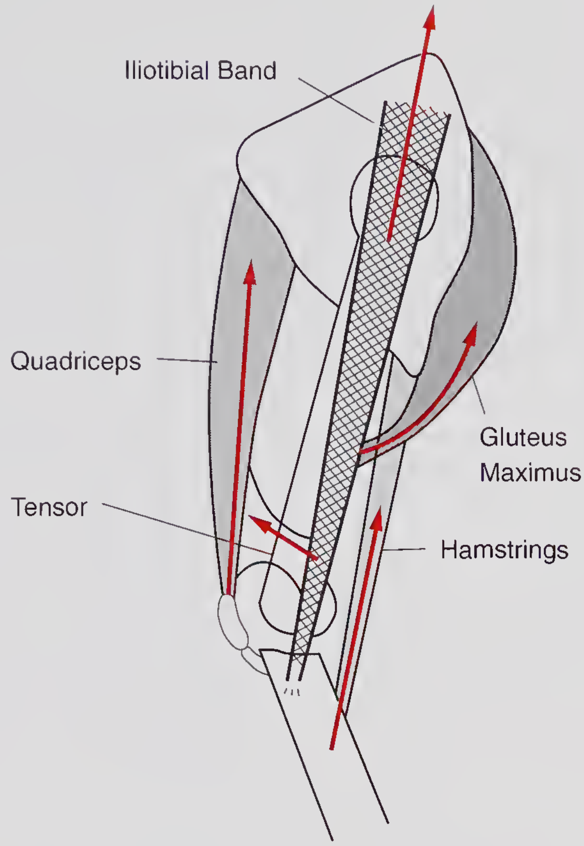


FIGURE 2.43

Musculature of Pelvis and Hip Joint Musculature of pelvis and hip joint.

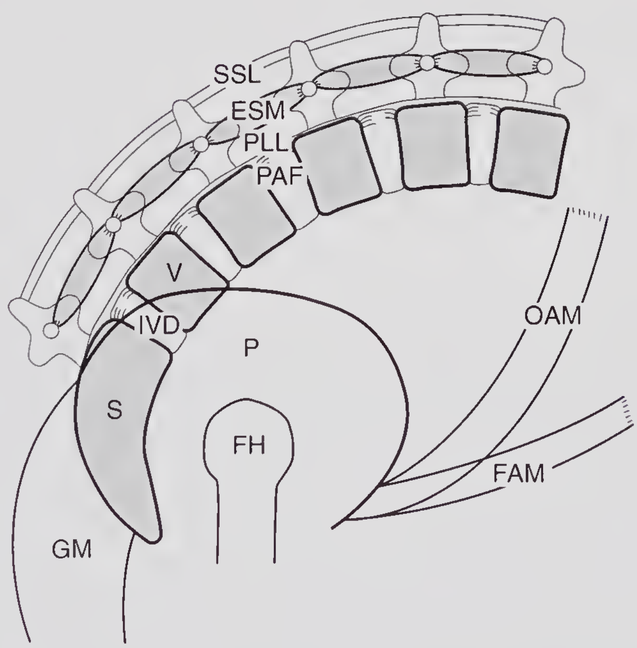


FIGURE 2.44

Muscular Ligamentous Support of Flexing Spine Structures vital to trunk flexion. V indicates vertebra; IVD, intervertebral disk; PAF, posterior annular fibers; PLL, posterior longitudinal ligament; ESM, extensor muscles of spine, SSL, supraspinous ligament; S, sacrum; GM, musculus gluteus maximus (greatest gluteal muscle); P, pelvis; FH, femoral head; OAM, oblique abdominal muscles and FAM, flexor abdominal muscles.

its musculature is termed the *passive subsystem* and cannot support the body weight.

Cervical injury mechanisms have measured load displacement behavior in relation to compression, shear, flexion, extension, lateral bending, and axial torque. From these studies the basis for instability has been expounded. Impaired capsular function of the facets also create instability, as does damage to the long ligaments of the spine.[34]

It is apparent that the extrafusal muscles afford stability to the osteoligamentous spine. All extraspinal muscle fibers are enclosed within a fascial sheath that elongates as the muscle lengthens and passively shortens as the muscle contracts.

The thoracolumbar fascia encloses all the erector spinal and quadratus lumborum muscles. The thoracolumbar fascia, by its attachments, stabilizes the erect spine and kinetically and mechanically reextends the spine from a forward flexed position. This fascia also flexes the spine laterally and assists in trunk rotation.

The erect spine is made stable by virtue of these fascial sheaths, which are made taut when the back muscles contract along with the deep oblique abdominal muscles, the transverse abdominal, and the latissimus dorsi, whose posterior insertions create the intracompartment of the erector muscles.

The transverse muscles are the activators of the anterior compartment (the abdominal "air bag") and with the latissimus dorsi activate the compartment of the erector spinal muscles. The other abdominal muscles—the obliques and the rectus abdominis—are essentially flexors and rotators, not stabilizers.

In any upper extremity action, there is contraction of the transverse muscles in "anticipation" of the pending action with trunk stabilization. This action is termed *feed forward* compared with *feedback* for a completed action.

Four major extrafusal muscles of the trunk furnish the stability of the trunk and the functions in the kinetic action in the thorax with upper extremity activities. These trunk muscles are the external and anterior oblique abdominal muscles and the transverse abdominal muscles (Figures 2.45, 2.46, 2.47).

The musculi quadratus lumborum are the extensor trunk muscles that coordinate in the "tubular" stability of the trunk (Figure 2.48).

This subsystem of spinal stability, the fascia forming the tubular structures, remain under control of sufficient isometric contraction of the trunk muscles. The transverse abdominal and the quadratus lumborum muscles are essential for spinal stability. The other abdominal flexor muscles are kinetic muscles that move the trunk in flexion, lateral flexion, and rotation, along with activity of the upper extremity. They should remain "quiet" when only stability is required.

In any upper extremity action, such as lifting, pushing, or pulling, the trunk must become stable, and it does so by contraction of the transverse abdominal muscles.

Certain occupational activities impose cyclic or prolonged trunk flexion postures, which have been proved to be detrimental, causing low back disorders. These cyclic or prolonged postures have caused "creeping" of adja-

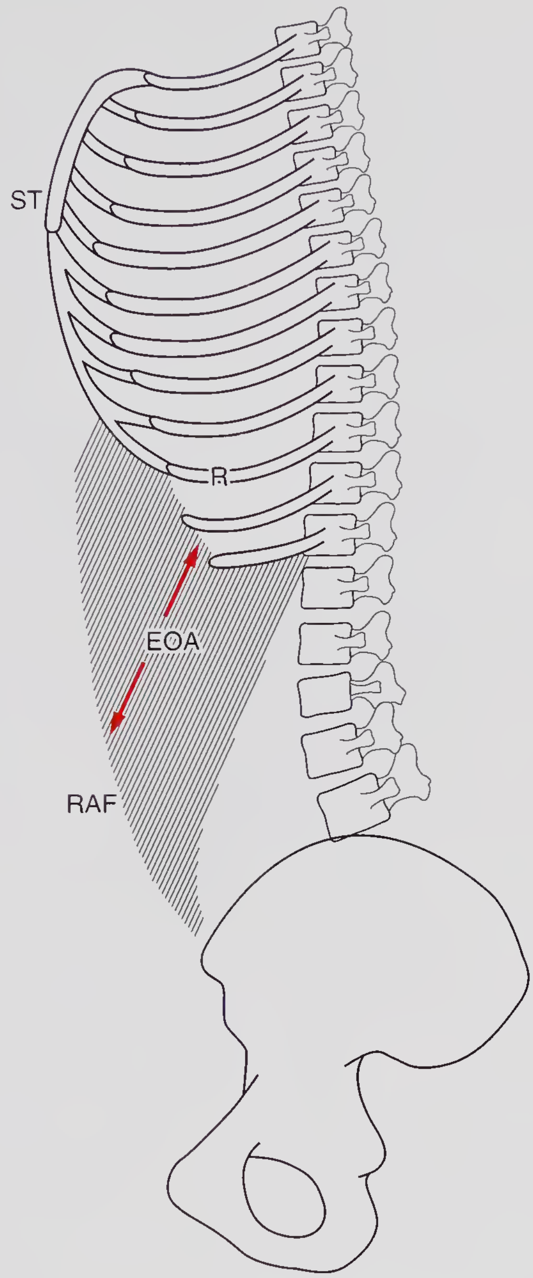


FIGURE 2.45

External Oblique Abdominal Muscles External oblique abdominal muscles (EOA) originate from lateral inferior surfaces of ninth to 12th ribs (R) and sternum (ST). They insert on anterior half of iliac crest and fascia of musculi rectus abdominis (RAF). EOA flexes spine forward and sideways.

cent vertebrae—the superior on the inferior. This "creep" cannot be attributed to laxity of ligaments or facet capsules. Studies imply that this creep is related to disk narrowing, which causes the instability. The fluid contents of the disk change over a 24-hour period due to compressive forces.[35-39] These compressive changes are accentuated in the cyclic and prolonged flexed postures, causing the disk to narrow. This narrowing, in turn, causes instability, as the ligaments and annular fibers are no longer under the same tension.

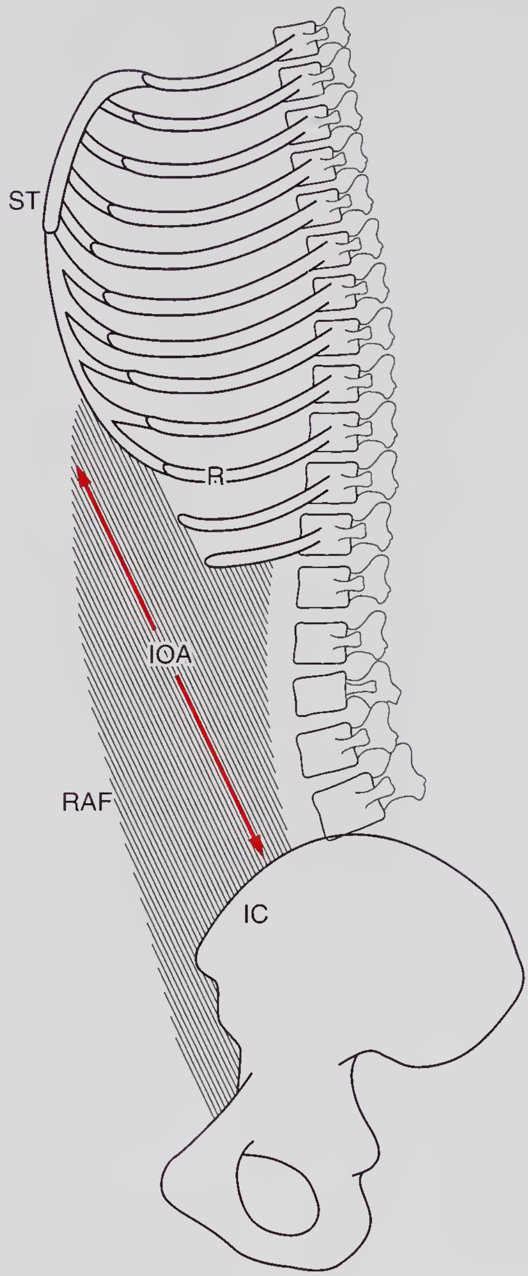


FIGURE 2.46

Internal Oblique Abdominal Muscles Internal oblique abdominal muscles (IOA) originate from lateral two thirds of inguinal ligament and anterior one third of iliac crest (IC). They insert on pubis and linea alba of fascia of musculi rectus abdominis (RAF). Their action is to flex and rotate trunk on pelvis.

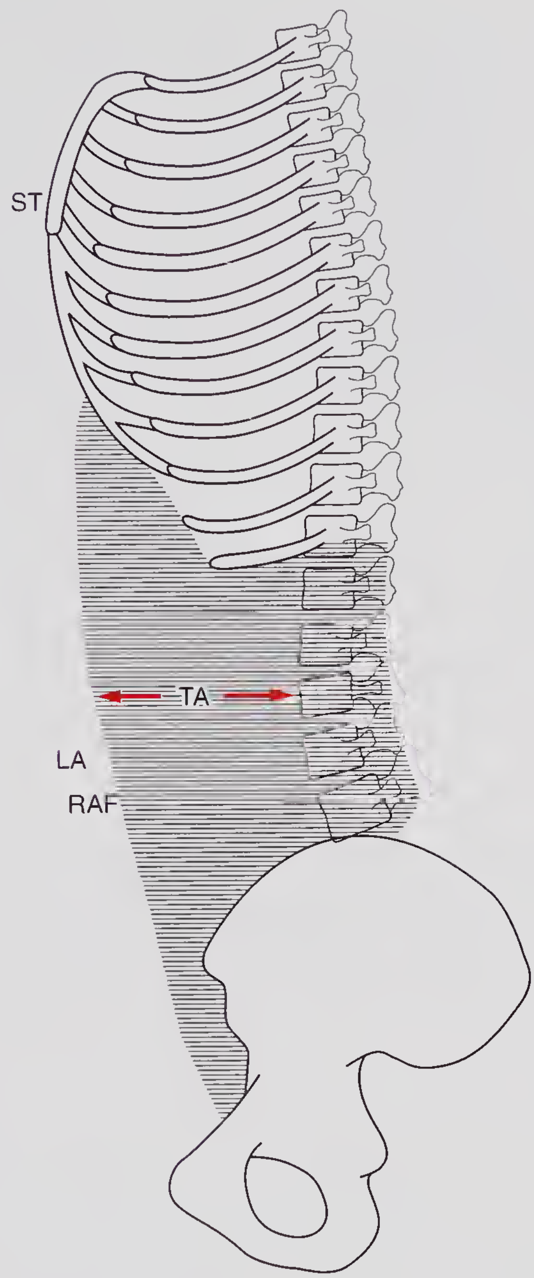


FIGURE 2.47

Transverse Abdominal Muscles Transverse abdominal muscle (TA) is the deepest abdominal muscle. These muscles originate from lateral one third of inguinal ligament, anterior two thirds of iliac crest (IC), inner edges of lower 6 rib costal cartilages, and sternum (ST). They insert on linea alba (LA) and fascia of musculi rectus abdominis (RAF). Their action is to constrict abdominal contents and enforce tubular abdominal cavity. Upon contraction of transverse abdominal muscles, an "air bag" is created by simultaneous contraction of diaphragm and pelvic muscles.

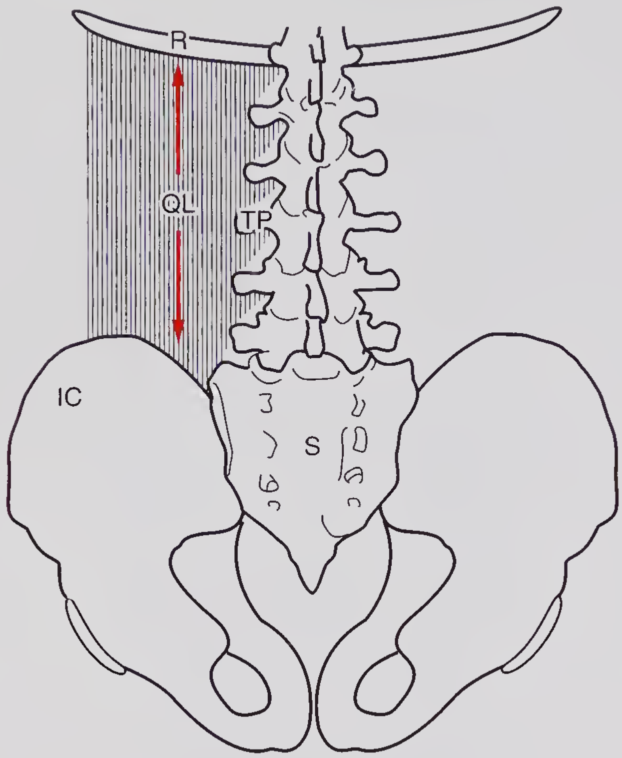


FIGURE 2.48

Quadratus Lumborum Musculi quadratus lumborum (QL) originate from iliolumbar ligament and posterior part of iliac crest (IC). They insert on inferior border of last rib (R) and transverse processes of upper 4 lumbar vertebrae. Their action is lateral flexion of lumbar vertebrae. By their attachments to erector spinal fascia, these muscles act as stabilizers. S indicates sacrum; TP, transverse processes.

The musculature, which has been stated as the major stabilizing force, is also destabilized in this "creeping" action because of loss of the ligamentous-muscular reflex. This reflex is initiated by the mechanoreceptors in ligaments, facet capsules, and even the annular fibers, which activate the muscles of that joint.

The mechanoreceptors of the spinal ligaments, disk, and joint capsule elicit reflex activity in the multifidus muscles of the spine, which is one of the stabilizing erector spinal muscles.[39,40] Fatigue of the muscles in cyclic and prolonged flexion possibly diminishes the protective muscle reflex and allows creep. Instability results from reduced protective reflexes from mechanoreceptor desensitization caused by laxity in the viscoelastic tissues of the spine—the ligaments and annular fibers (Figure 2.49).

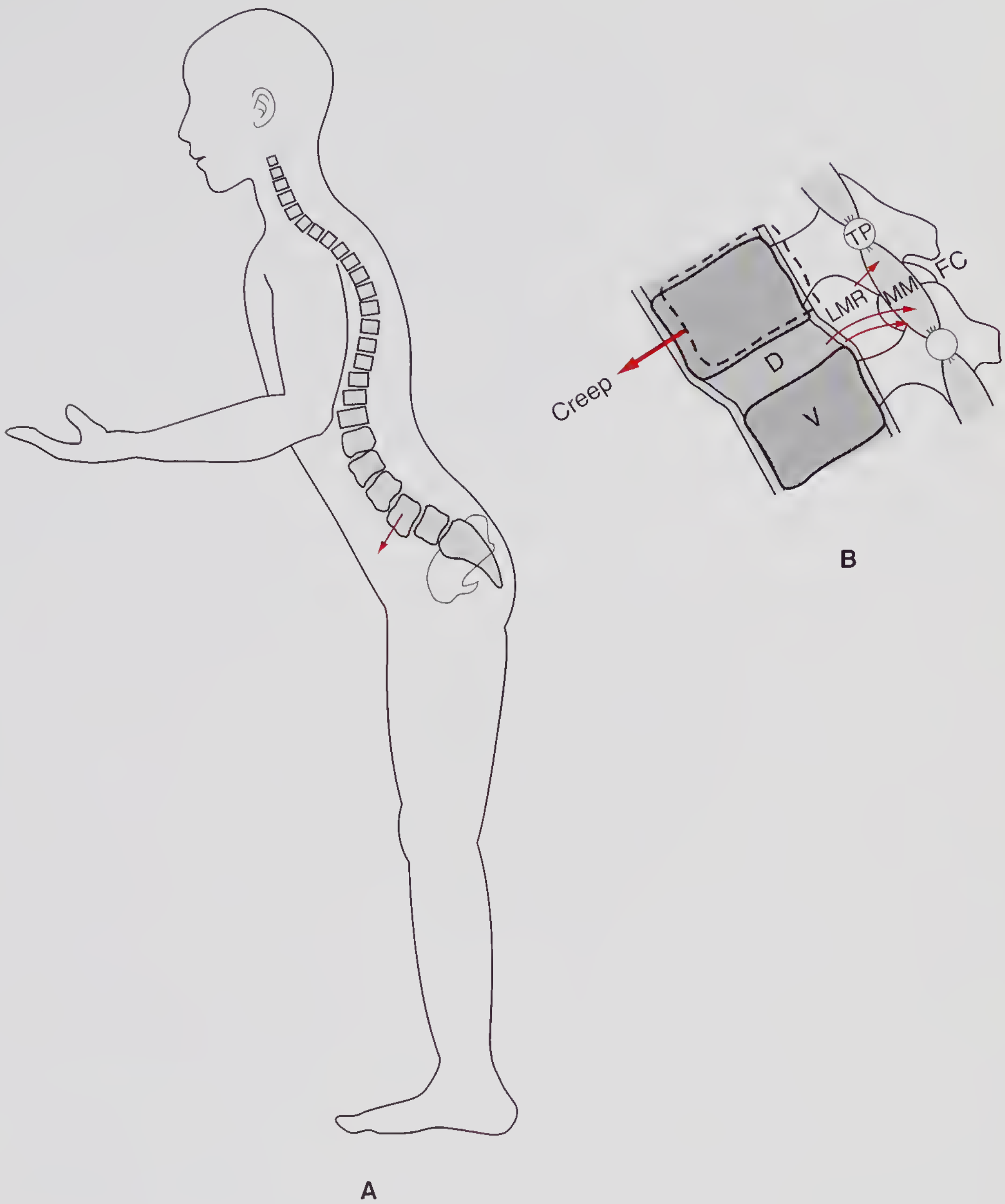


FIGURE 2.49

Protective Ligamentous-Muscular Reflex A, Cyclic or prolonged flexed position causes ultimate reflex from irritation of the proprioceptive nerves in the tissue from creep of the vertebrae. B, Tissues shown in the right contain proprioceptive nerve endings. LMR indicates ligamentous-muscular reflex; D, disk; V, vertebra; TP, transverse process; MM, multifidus muscles; and FC, facet capsule.

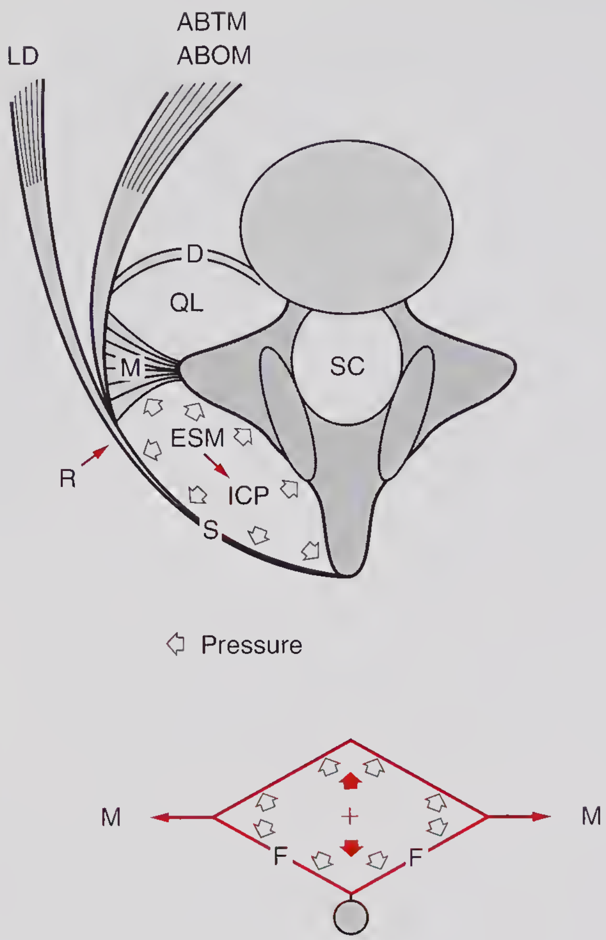


FIGURE 2.50

Intracompartmental Pressures Latissimus dorsi (LD), internal oblique abdominal (ABOM), and transverse internal abdominal (ABTM) muscles merge at raphe (R) and send fascial sheaths (F) that encircle musculus quadratus lumborum (QL) and connect to transverse process (TP) of vertebrae. Posterior sheath (S) surrounds erector muscles of spine (ESM). Compartment formed acts as tubular structure that stabilizes spinal column. SC indicates spinal canal; D, disk; M, multifidus muscle; and ICP, intracompartmental pressure.

Stability of the Static Spine

The erect spine and the spine during any physical activity remain stable by the extrafusal muscles of the trunk and their fascia by the formation of "tubular" structures. The tendons and the fascia of the trunk muscles and the latissimus dorsi muscle combine at the raphe, sending sheaths that encircle the extensor muscles—the quadratus lumborum and the erector muscles of the spine. The compartments formed are located posteriorly, and with the anterior compartment of the abdominal cavity, they afford stability of the vertebral column (Figures 2.50, 2.51, 2.52, 2.53).

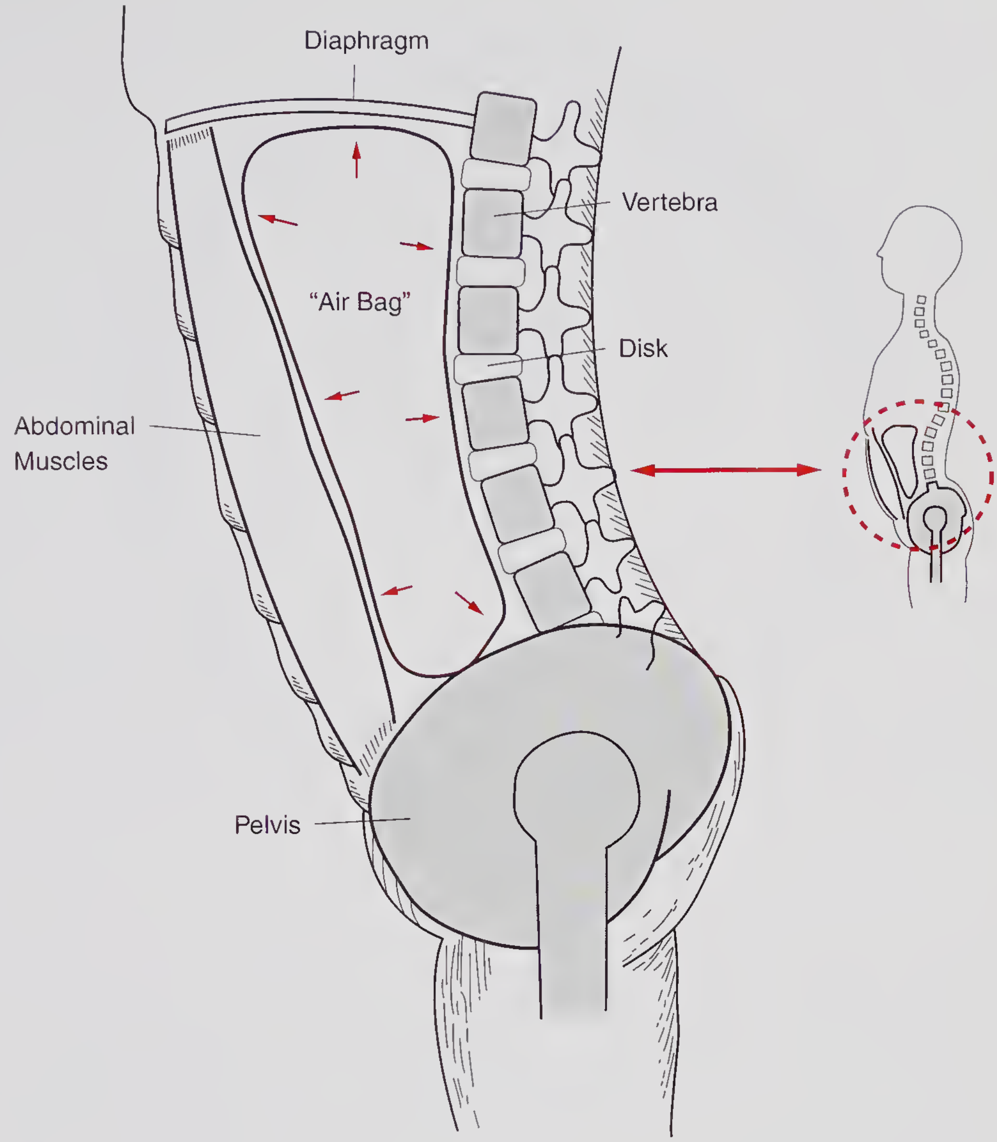


FIGURE 2.51

Abdominal "Air Bag" Concept "Air bag" concept of support of spine is based on a "bag" in abdominal cavity, with diaphragm superior to bag, pelvis inferior, abdominal muscles anterior, and spine posterior.

Stability of the spine has been proposed as occurring from contraction of the deep vertebral muscles—intersegmental intertransversalis and interspinalis, lumbar multifidus, longissimus thoracis pars lumborum, and the medial fibers of the quadratus lumborum (Figure 2.54).

These muscles are primarily extensors of the low back when they contract bilaterally but are lateral flexors and rotators when they contract unilaterally. These small muscles are considered "spinal segmental stabilizers" of the lumbar spine.[41] The other trunk muscles, the external oblique

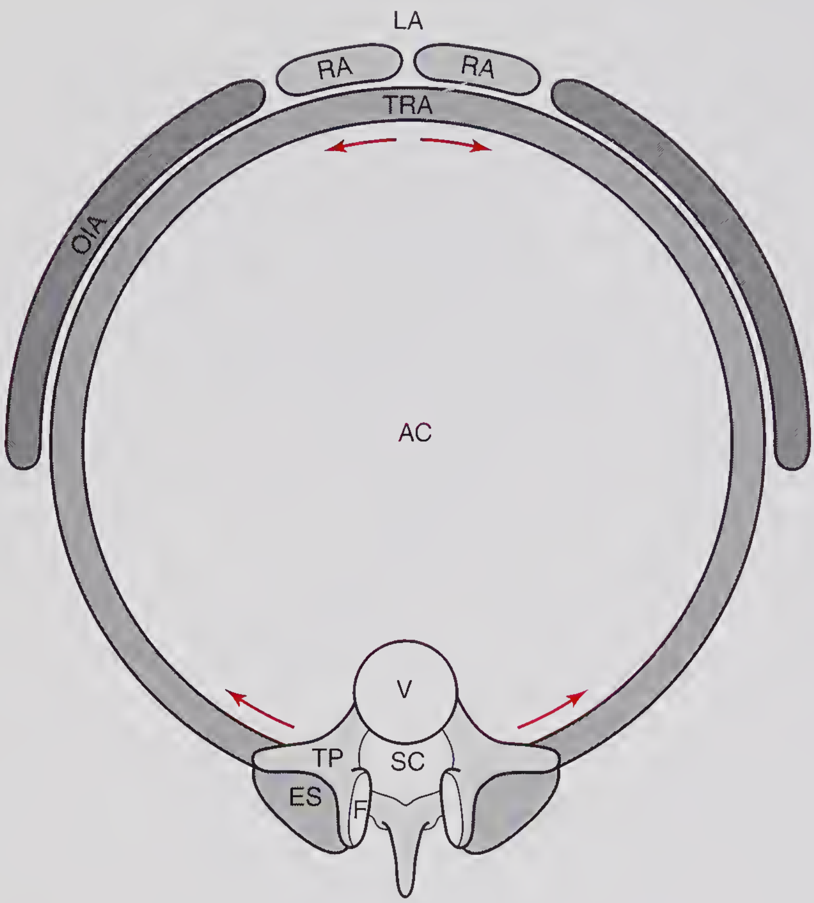


FIGURE 2.52

Components of "Air Bag" Abdominal cavity (AC) is completely surrounded by transverse abdominal muscles (TRA), whose horizontal fibers attach posteriorly to fascia of compartment containing quadratus lumborum and erector spinal (ES) muscles. Abdominal muscles that are more superficial are internal oblique (OIA), whose fibers run obliquely, and rectus abdominus (RA), whose fibers run vertically and fuse anteriorly at linea alba (LA). OIA muscle rotates trunk, and RA flexes trunk. V indicates vertebrae; F, facets; TP, transverse processes; and SC, spinal canal.

and internal oblique, are "global" muscles, in that they activate the spine, whereas the small intrinsic muscles stabilize the spine. Weakness or failure of these small muscles to contract has been found to be the cause of functional impairment of the low back.

It has been postulated that before any major activity that displaces the body mass, there occurs a "feed forward" reflex activity of the central nervous system that instantaneously alerts and prepares the total body mass for the impending action. This reflex action activates the muscles of

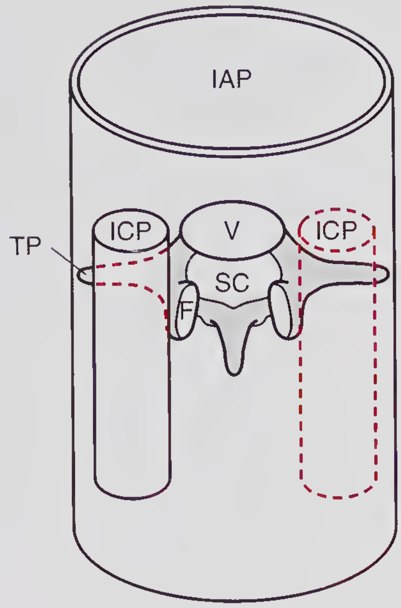


FIGURE 2.53

Tubular Concept of Spinal Column Stability Spine is supported by 3 tubular structures: intra-abdominal pressure (IAP) and intracompartmental pressure (ICP). Spinal functional unit consists of 2 adjacent vertebrae (V), facets (F), transverse processes (TP), and spinal canal (SC).

the trunk to minimize the postural disturbance caused by the upper extremity and any weights held away from the body.[42,43] This action has been termed *feed forward* compared with the term *feedback*, when the central nervous system is informed that the intended action has been accomplished.

As an upper extremity moves away from the center of gravity, it causes the center of the body mass to move in the opposite direction to maintain balance. In essence, as the arms move forward, the body mass moves backward. As the upper extremity moves to one side, the body mass moves to the opposite side. This movement activates the appropriate trunk muscles[44-47] (Figure 2.55, 2.56).

The superficial abdominal flexor muscles accommodate the shift of the body. However, the exact opposite occurs if the upper extremity extends rather than flexes, during which the body mass moves in the opposite direction.

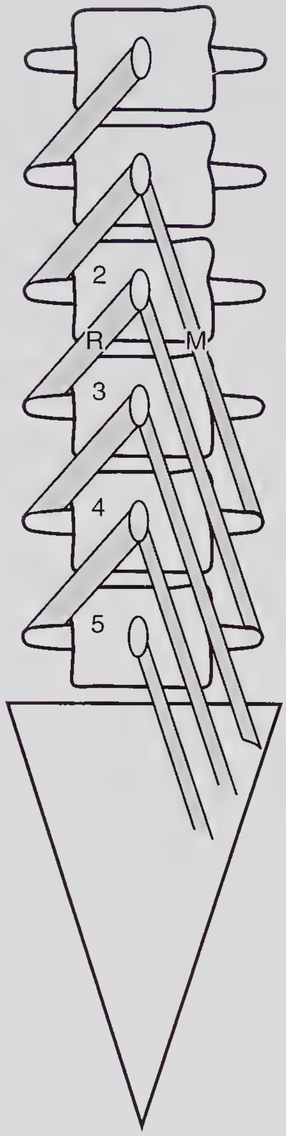


FIGURE 2.54

Lumbar Multifidus Muscles Multifidus muscles (M), the most medial of lumbar muscles, connect vertebra to vertebra. They have 5 bands that connect spinous processes together and adjacent lamina between lumbar vertebrae and sacrum. R indicates rotator muscles.

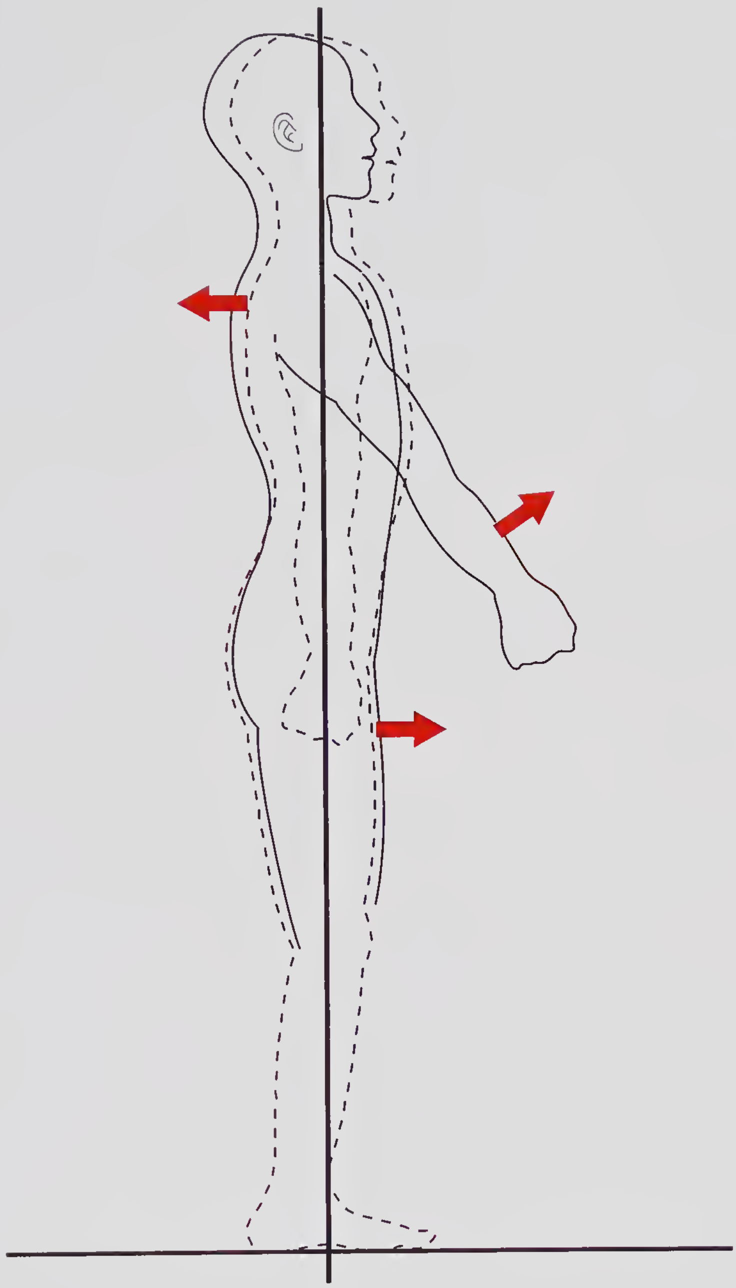


FIGURE 2.55

"Feed Forward" Motion Erect body (dotted lines) in its relationship to center of gravity moves backward (arrow pointing left) as arm moves forward. Simultaneously, pelvis moves forward (arrow pointing right).

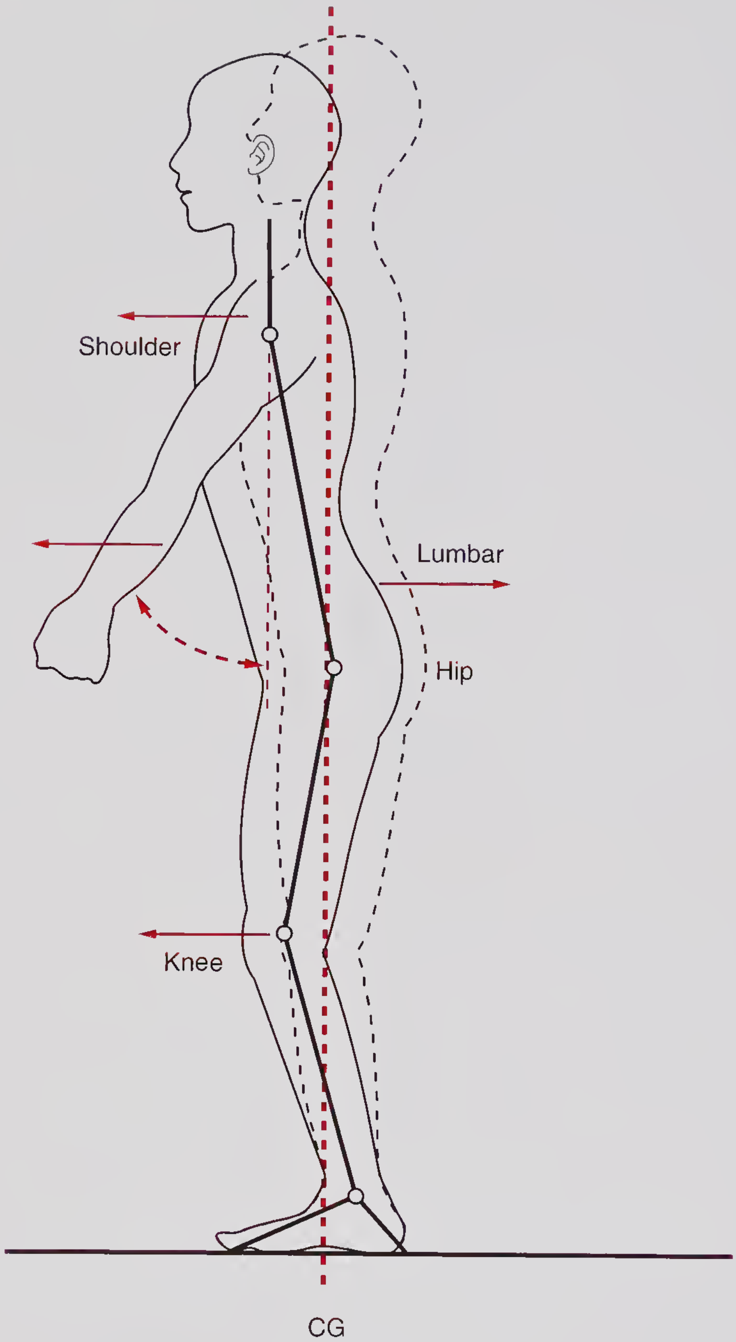


FIGURE 2.56

Preparatory Trunk Muscle Activity Body (dotted lines) is shown with arm dependent. As arm moves forward (curved, broken arrow) at shoulder, thorax and head move ahead of center of gravity (CG). Low back extensor muscles become activated backward, and hips move forward.

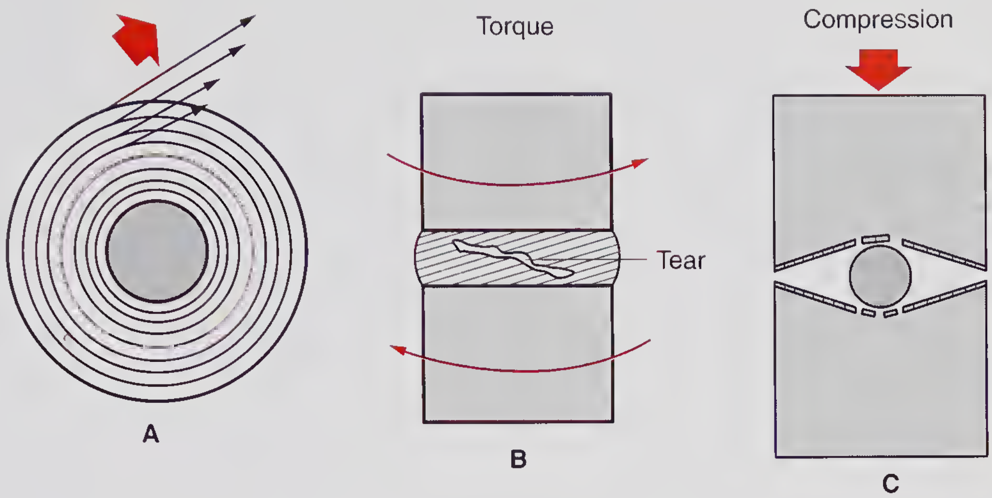


FIGURE 2.57

Compressive and Torque Forces on the Intervertebral Disk A, Rotational (torque) forces on annular fibers of disk. B, Resulting annular tears from rotational forces. C, Excessive force may break vertebral end plates before rupturing disk.

FUNCTIONAL ANATOMY OF DISCOGENIC DISEASE

Many terms are applied to discogenic "disease": *slipping*, *bulging*, *internal herniation*, *rupture*, *extrusion*, *degeneration*, and so on. Therefore, some clarification of the functional anatomy and its impairment is indicated.

It has been well documented that compressive forces combined with rotational forces are the prime factors leading to annular tearing that disrupts the annulus surrounding and containing the nucleus pulposus (Figure 2.57).

The nucleus pulposus that no longer is contained within the intact annulus protrudes in numerous directions, with varying clinical manifestations (Figure 2.58).

Internal herniation of the nucleus causes external protrusion of the remaining annular sheaths, with encroachment on the nerve roots in the foramen (Figure 2.59). If the torn annular fibers allow the nucleus to externally herniate, it is termed a *disk extrusion* or a *true herniation* (Figure 2.60).

With disk degeneration, the hydrophilic capacity of the disk is lost and the vertebral end plates approximate (Figure 2.61).

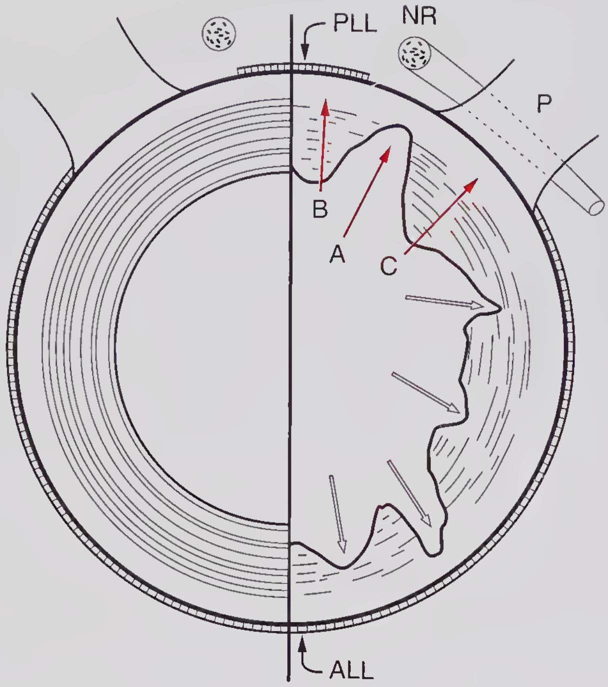


FIGURE 2.58

Directions of Internal Nucleus Herniation Left half of disk is normal. Tearing of annular fibers (A) allows protrusion of nucleus toward lamina (B) but does not encroach on posterior longitudinal ligament (PLL) or nerve root (NR), which reside within foramen. P indicates pedicle; ALL, anterior longitudinal ligament; and C, profusion toward pedicle with no nociception.

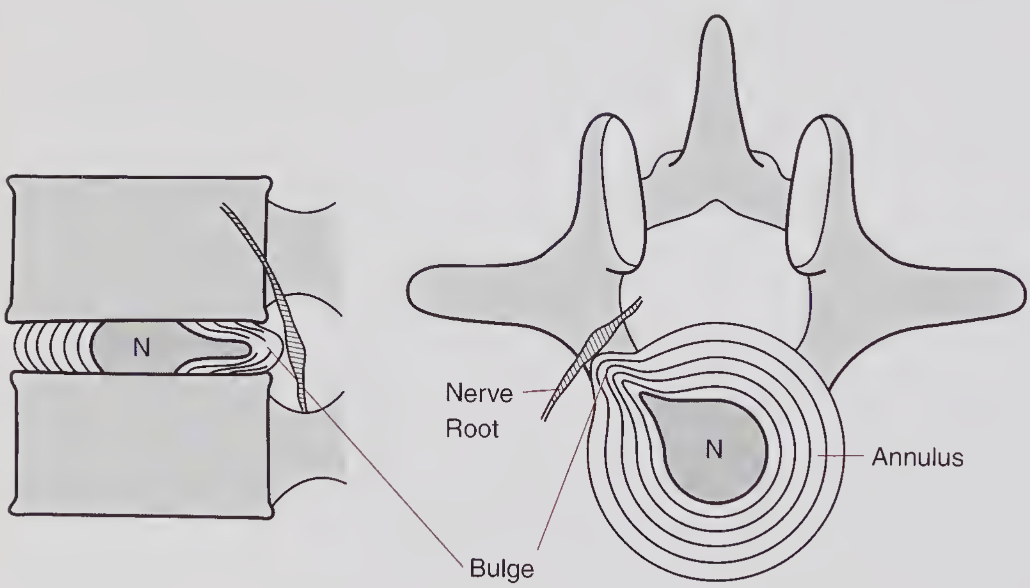


FIGURE 2.59

Internal Nucleus Protrusion Central disk protrusion of nucleus (N) may cause outer remaining intact fibers to protrude (bulge) and encroach on nerve root.

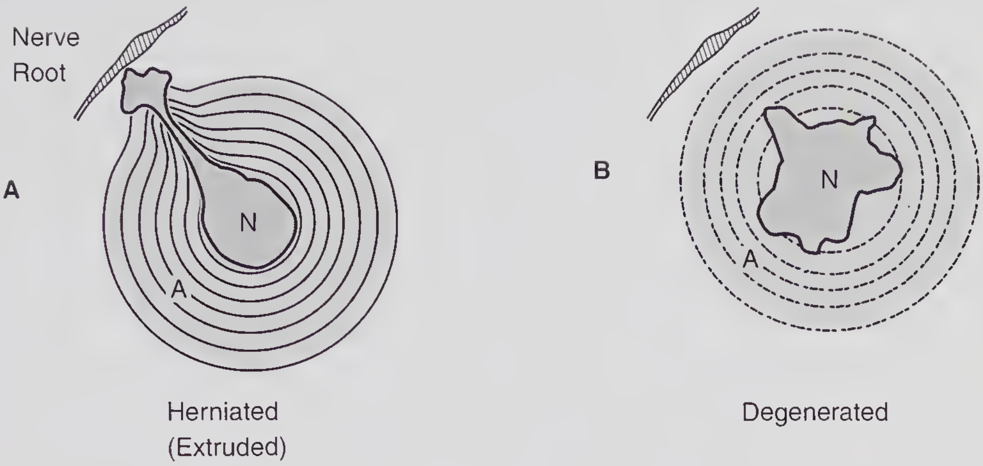


FIGURE 2.60

Disk Extrusion A, Internal nuclear herniation through torn outer annular fibers (A), which extrude out of disk and encroach on the nerve root. B, Degeneration of disk without herniation.

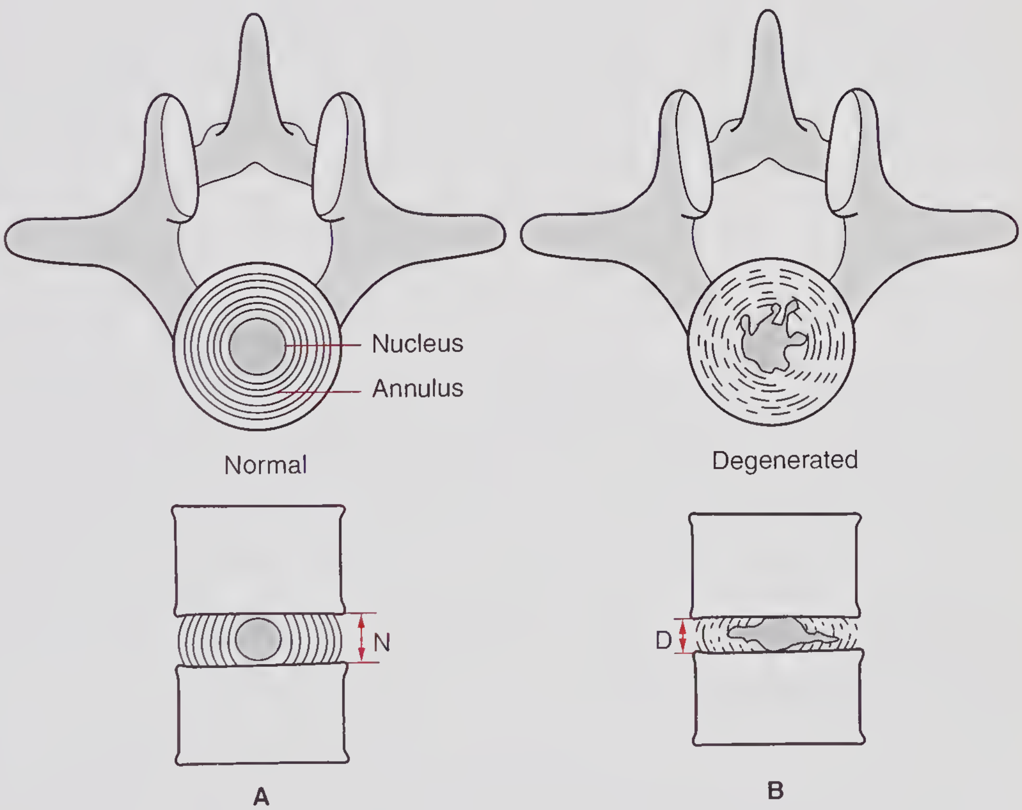


FIGURE 2.61

Disk Degeneration A, Normal disk. B, Disk degeneration with loss of hydration causing narrowing of disk space between vertebrae.

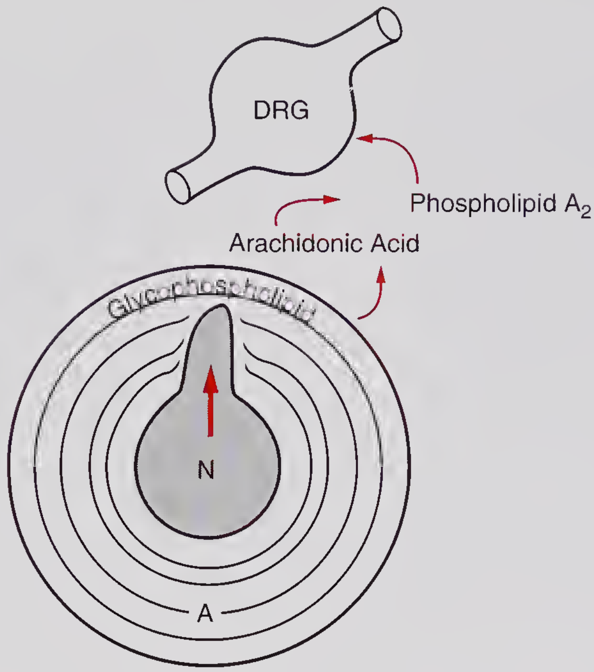


FIGURE 2.62

Chemical Radiculitis Chemical breakdown of matrix, with ultimate formation of phospholipid A_2, which chemically irritates dorsal root ganglion (DRG). N indicates nucleus; A, annular fibers.

The idea of pathological encroachment on a nerve root and its dura causing radiculitis simply from pressure is now refuted. The clinical symptoms are now attributed to chemical irritation of the nerve and its dura from a breakdown of the glycophospholipid of the disk into arachidonic acid. The arachidonic acid then breaks down to phospholipid A_2, thus making pressure noxious and the cause of radicular pain (Figure 2.62).

NEUROLOGICAL SYSTEM OF THE LUMBAR SPINE

All of the motor and sensory components of the lumbar spine need evaluation. The central nervous system from the cortex to the cord has been discussed, and the final pathway is the nerve root, which emerges at the foramen (Figures 2.63, 2.64).

The nerve forming the cauda equina originates at the conus of the cord the T12 vertebra and fans out in an equine shape (Figures 2.65, 2.66). Each nerve root is enclosed in a dural sheath (Figures 2.67, 2.68, 2.69).

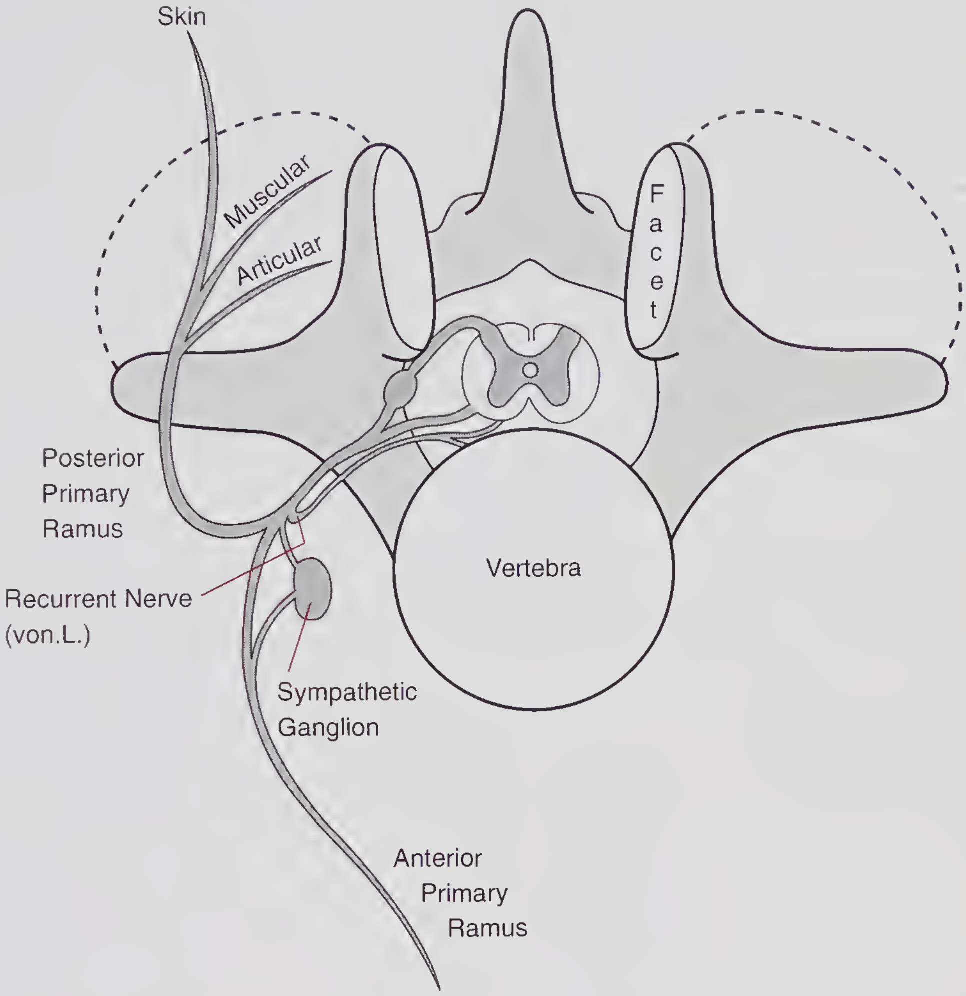


FIGURE 2.63

Components of Nerve Root Nerve roots of cauda equina are similar to nerve roots at higher levels. Root that leaves spinal cord has sensory and motor components. Once it emerges from foramen, it branches into anterior primary division and posterior primary division. Sympathetic nerve has a ganglion near vertebral column and sends a branch back through foramen as recurrent nerve of Luschka, which is the sensory nerve to most components of functional unit. Anterior primary division descends into lower extremities, and posterior primary division supplies erector muscles of spine, skin, and articular branch to facets.

As the nerve emerges through the foramen, it passes the disk at each level (Figures 2.70, 2.71, 2.72).

The recurrent nerve of Luschka, which innervates most of the vital segments of the functional unit, contains sympathetic as well as somatic nerves (Figures 2.73, 2.74).

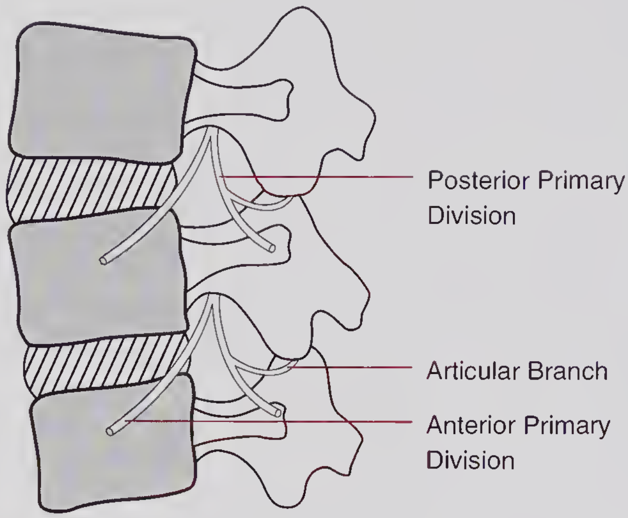


FIGURE 2.64

Emergence of Nerve Roots through Foramen Viewed laterally, nerve roots emerge from foramen and divide into anterior and posterior primary divisions. Small articular branch is sensory to facet joints.

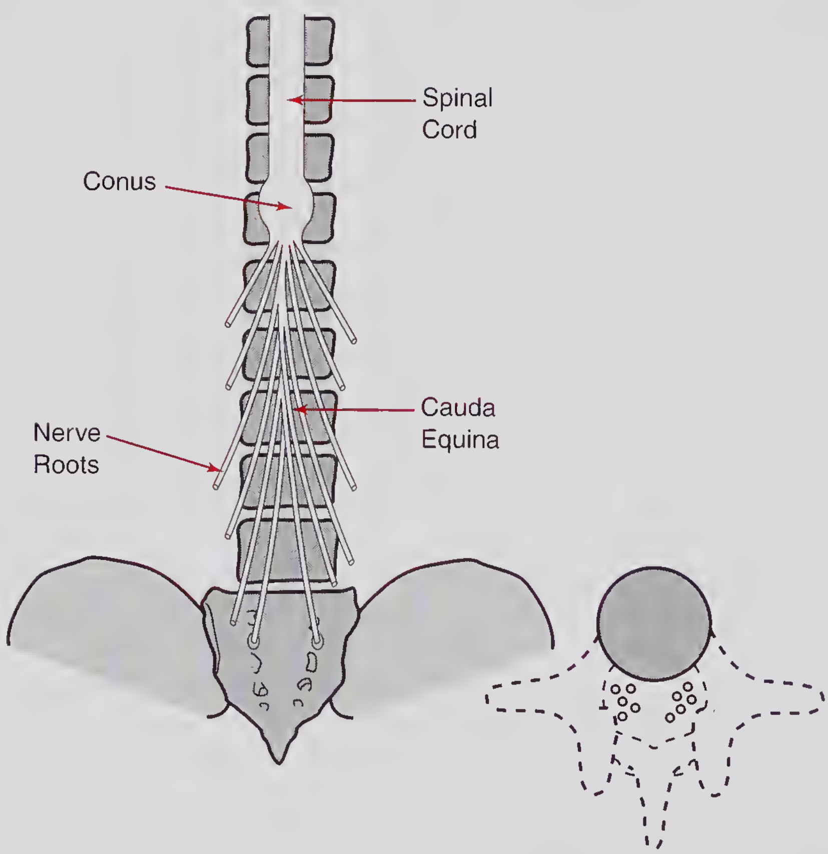


FIGURE 2.65

Formation of Cauda Equina Spinal cord ends at T12 vertebra as a conus and divides into nerve roots forming cauda equina. Small bottom figure is view of cauda equina from behind within spinal canal.

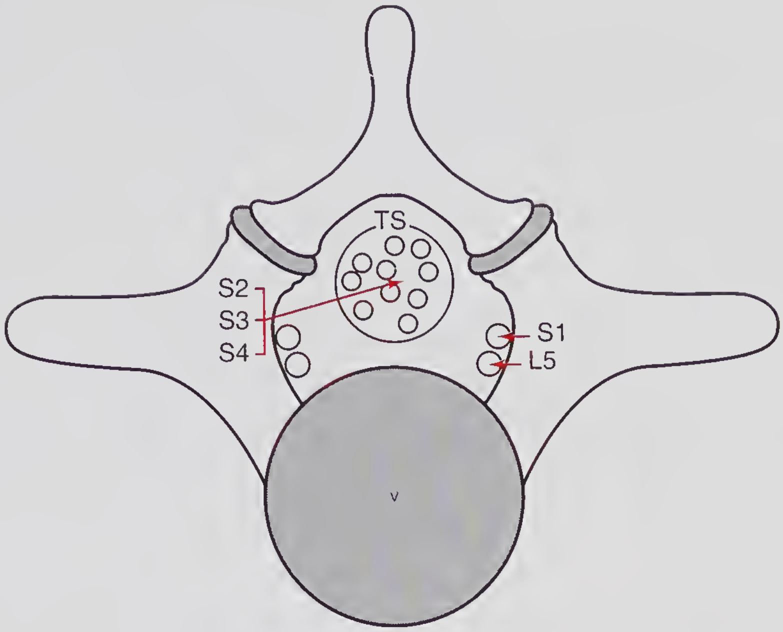


FIGURE 2.66

Vertical View of Cauda Equina Roots of cauda equina viewed from above at L5-S1 spinal level show nerve roots enclosed in thecal sac (TS) and also show sacral roots (S1, S2, S3, S4). V indicates vertebra.

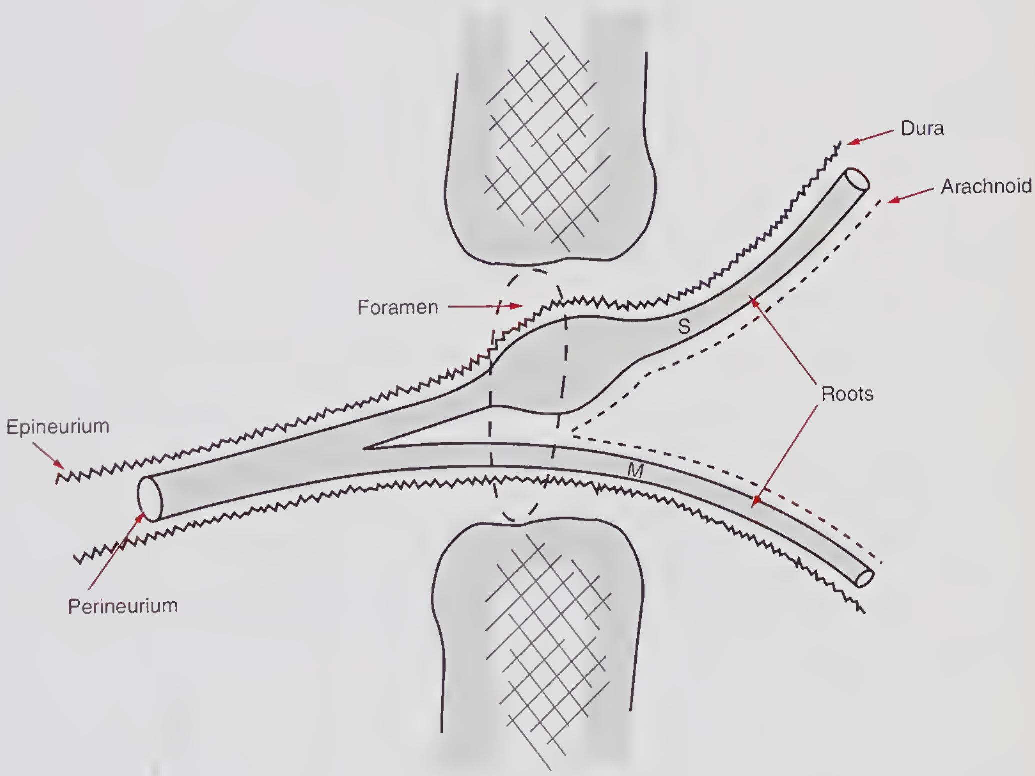


FIGURE 2.67

Dural and Arachnoid Sheaths of Nerve Root Nerve roots, both sensory (S) and motor (M), merge at intervertebral foramen enclosed within a sheath formed by arachnoid and dura. Arachnoid terminates at foramen, and dura continues and becomes epineurium and perineurium.

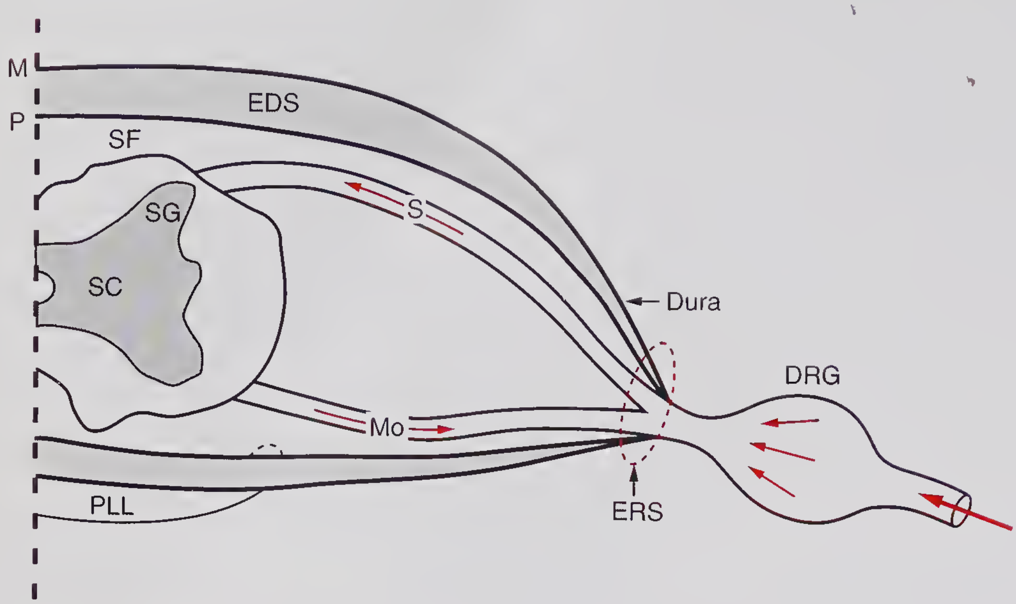


FIGURE 2.68

Dural Sheaths of Nerve Roots Spinal cord (SC) is source of nerve roots—motor (Mo) and sensory (S)—with the latter ending in substantia gelatinosum (SG). Roots are enclosed in dura, which has 2 layers—meningeal (M) and parietal (P)—forming extradural space (EDS), which contains spinal fluid. Both dural layers end at external residual septum (ERS). Roots pass through dorsal root ganglion (DRG). PLL indicates posterior longitudinal ligament.

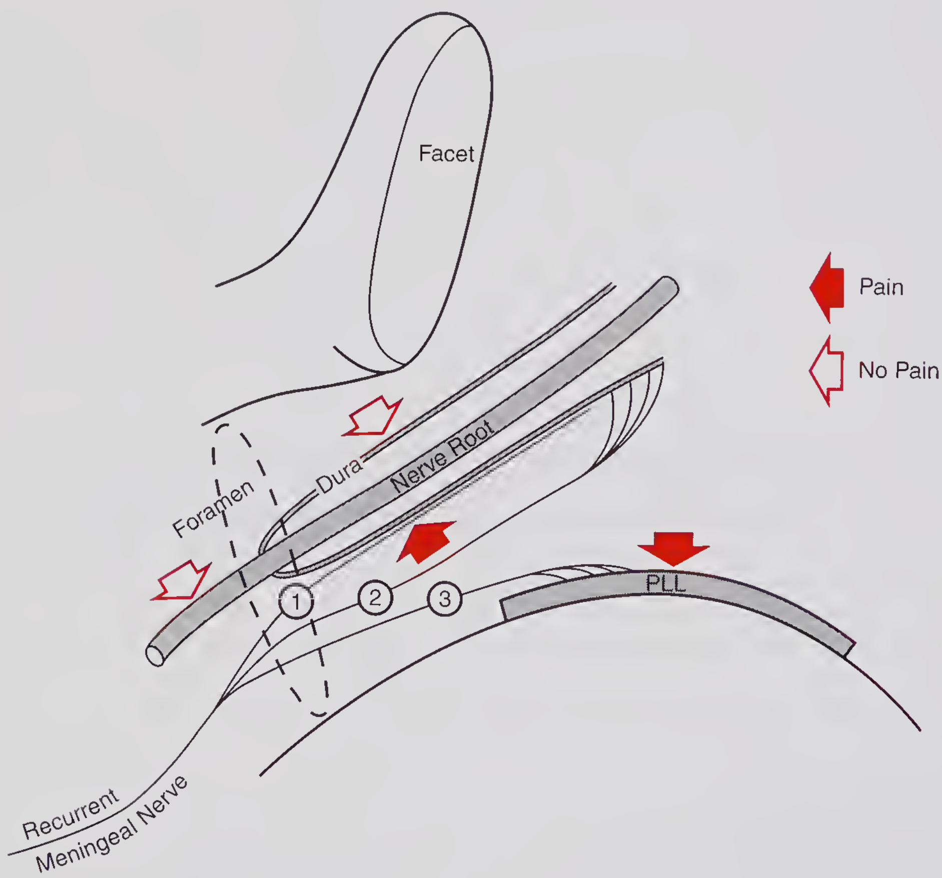


FIGURE 2.69

Dura Accompanying Nerve Root Dura accompanies nerve root through foramen along with recurrent meningeal nerve. Meningeal nerve divides into 3 branches. Branches 1 and 2 supply dura, and 3 supplies posterior longitudinal ligament (PLL).

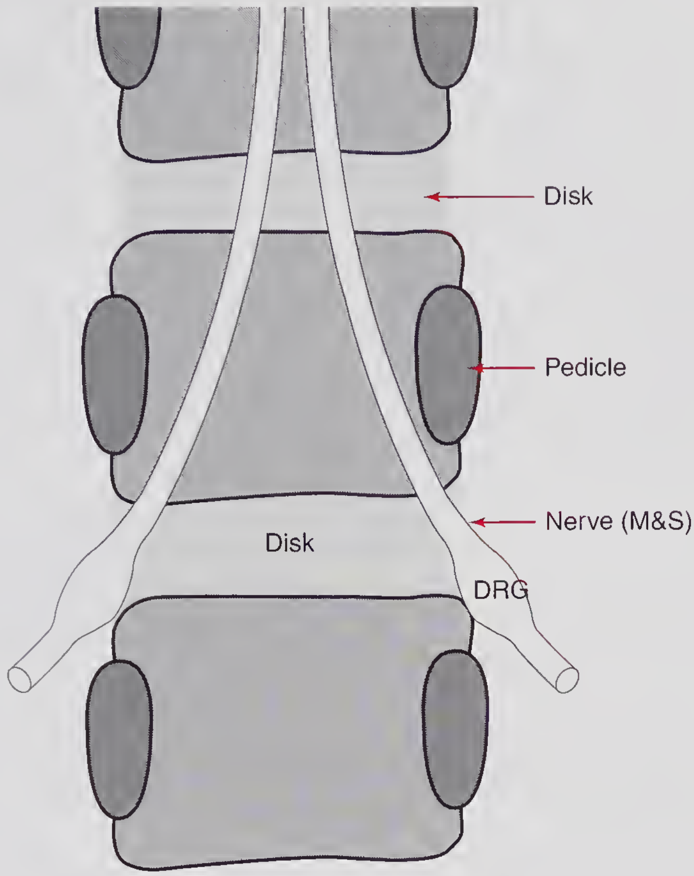


FIGURE 2.70

Nerve Root Relationship to Intervertebral Disks Nerve root containing motor and sensory (M&S) fibers passes under pedicle and over posterior lateral aspect of disk at each level. DRG indicates dorsal root ganglion.

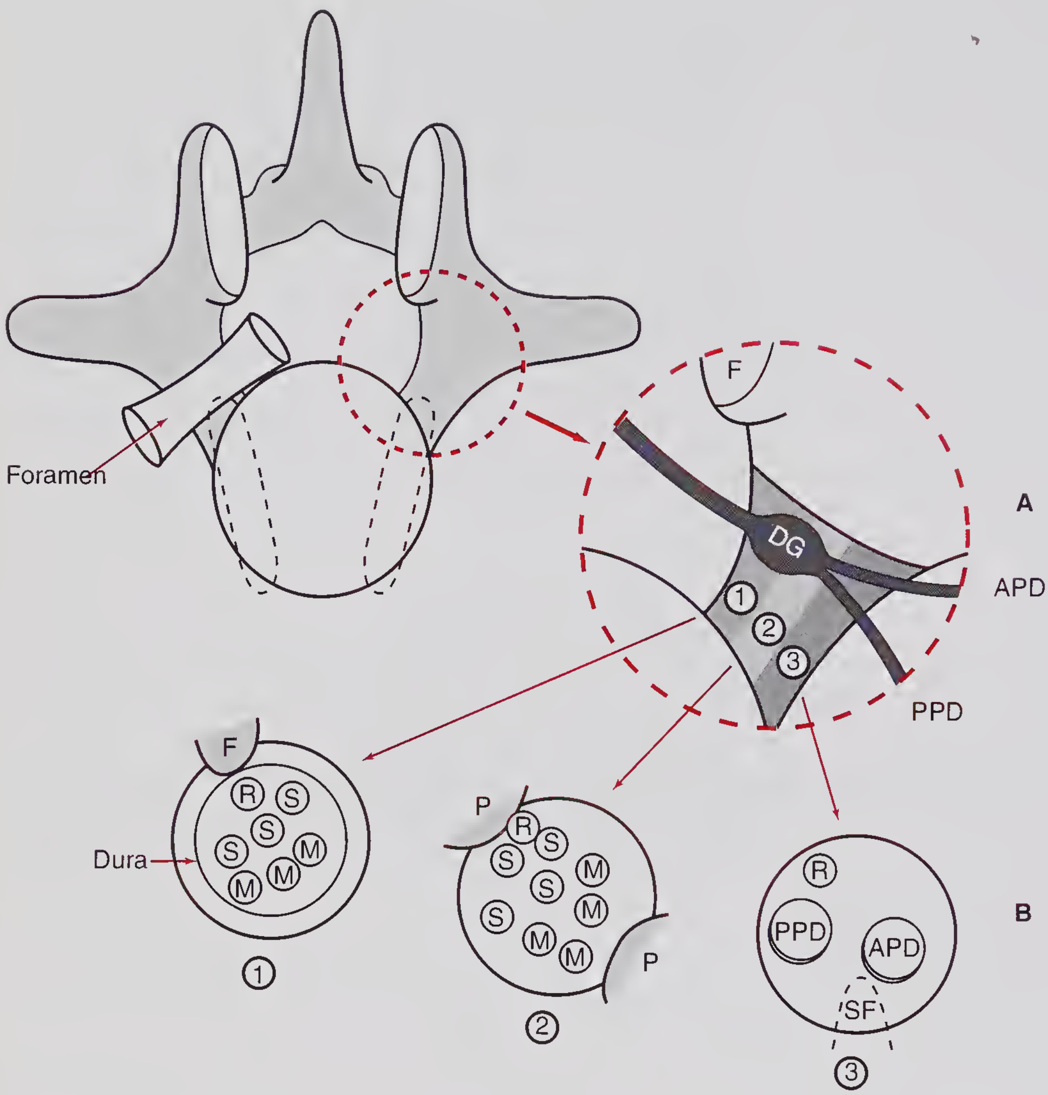


FIGURE 2.71

Normal Contents of Intervertebral Foramen A, Foramen as funnel-shaped tubular opening. Its contents within foramen (dotted circle) are facet (F), dorsal root ganglion (DG), and nerve roots at 3 levels. B, 1 indicates proximal portion of foramen containing sensory (S) and motor (M) roots; 2, roots near center of foramen pedicles (P); and 3, distal outer edge of foramen containing posterior primary divisions (PPD). R indicates recurrent nerve of Luschka; SF, superior facet; and APD, anterior primary divisions.

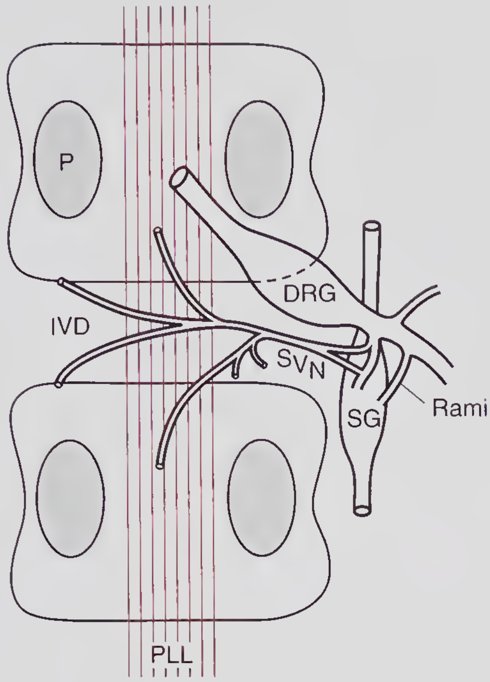


FIGURE 2.72

Sinovertebral Nerve Dorsal root ganglion (DRG) emerges laterally, giving off ramus branches to spinal ganglion (SG), from which emerge sinovertebral nerve (SVN), posterior longitudinal ligament (PLL), and intervertebral disk (IVD). The sinovertebral nerve originates from the intermediolateral cell column of the cord and innervates the nerve root dura, posterior longitudinal ligament, and the outer annular layers of the disk. P indicates pedicles.

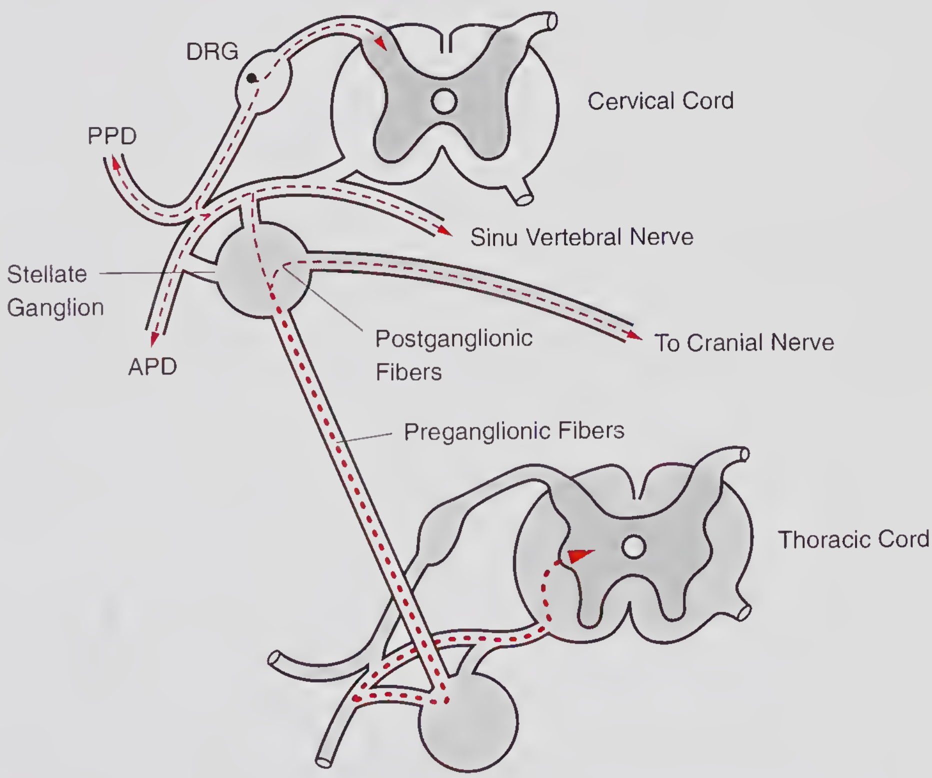


FIGURE 2.73

Formation of Sympathetic Nervous System Upper portion shows spinal cord with the anterior primary division (APD), posterior primary division (PPD), and dorsal root ganglion (DRG). Preganglionic fibers begin at thoracic cord, enter ganglion, and leave as postganglionic fibers to peripheral nerve.

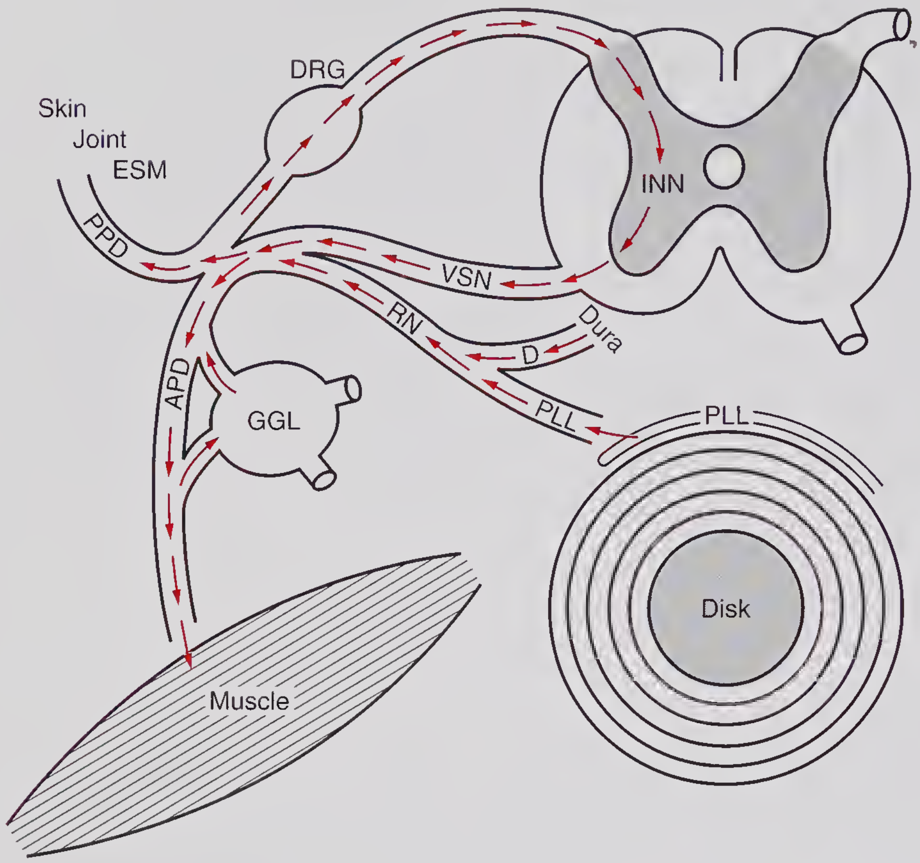


FIGURE 2.74

Innervations of Recurrent Meningeal Nerve Sensory fibers come from skin, joints, and extraspinal muscles (ESM). They ascend posterior primary division (PPD) through dorsal root ganglion (DRG). On entry into cord gray matter, they send branches through internuncial branches (INN) through ventral sensory nerve (VSN) to muscles via anterior primary division (APD). GGL indicates sympathetic ganglion; RN, recurrent nerve; D, dura; and PLL, posterior longitudinal ligament.

REFERENCES

1. Bogduk N. Structure and function of the lumbar spine. In: Mayer TG, Mooney V, Gatchel RJ, eds. *Contemporary Conservative Care for Painful Spinal Disorders*. Philadelphia, Pa: Lea & Febiger; 1991.
2. Gracovetsky S. *The Spinal Engine*. New York, NY: Springer-Verlag; 1989.
3. Tillman LJ, Cummings GS. Biological mechanisms of connective tissue mutability. In: Currier DP, Nelson RM, eds. *Dynamics of Human Biologic Tissues*. Philadelphia, Pa: FA Davis Co; 1992.
4. Eyre DR. Collagen of the disc. In: Ghosh P, ed. *The Biology of the Intervertebral Disc*. Elkins Park, Pa: Franklin Book Co; 1988.
5. Bogduk N. *Clinical Anatomy of the Lumbar Spine*. Edinburgh, Scotland: Churchill Livingstone; 1987.
6. Nachemson AL, Schultz AB, Berkson MH. Mechanical properties of human lumbar spine segments: influence of age, sex, disc level, and degeneration. *Spine*. 1979;4:1-8.
7. Cailliet R. *Understand Your Backache*. Philadelphia, Pa: FA Davis; 1984:17.

8. Abumi K, Panjabi MM, Kramer KM, Duranceau J, Oxland T, Crisco JJ. Biomechanical evaluation of lumbar spinal stability after graded facetectomies. *Spine*. 1990;15:1142-1147.
9. Adams MA, Hutton WC. The relevance of torsion to the mechanical derangement of the lumbar spine. *Spine*. 1981;6:241-248.
10. Bogduk N, Macintosh JE, Pearcy MJ. A universal model of the lumbar back muscles in the upright position. *Spine*. 1992;17:897-913.
11. Macintosh JE, Bogduk N, Pearcy MJ. The effects of flexion on the geometry and actions of the lumbar erector spinae. *Spine*. 1993;18:884-893.
12. Lovett RW. The mechanism of the normal spine and its relation to scoliosis. *Boston Med Surg J*. 1905;13:349-358.
13. Lovett RW. *Lateral Curvature of the Spine and Round Shoulders*. Philadelphia, Pa: Blakiston's Son and Co; 1907.
14. Marras WS, Lavender SA, Leurgans SE, et al. The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders: the effects of workplace factors, trunk position, and trunk motion characteristics on risk of injury. *Spine*. 1993;18:617-628.
15. Panjabi M, Yamamoto I, Oxland T, Crisco J. How does posture affect coupling in the lumbar spine? *Spine*. 1989;14:1002-1011.
16. Morgan FP, King T. Primary instability of lumbar vertebrae as a common cause of low back pain. *J Bone Joint Surg*. 1957;39:6-22.
17. Swanepoel MW, Adams LM, Smeathers JE. Morphometry of human apophyseal joints: a novel technique. *Spine*. 1997;22:2473-2483.
18. Pearcy MJ, Tibrewal SB. Axial rotation and lateral bending in the normal lumbar spine measured by three-dimensional radiography. *Spine*. 1984;9:582-587.
19. Farfan HF, Cossette JW, Robertson GH, Wells RV, Kraus H. The effects of torsion on the lumbar intervertebral joints: the role of torsion in the production of disc degeneration. *J Bone Joint Surg Am*. 1970;52:468-497.
20. Gracovetsky S, Farfan H. The optimum spine. *Spine*. 1986;11:543-573.
21. Cholewicki J, McGill SM. Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain. *Clin Bimech*. 1996;11:1-15.
22. McGill SM. A myoelectrically based dynamic three-dimensional model to predict loads on lumbar spine tissues during lateral bending. *J Biomech*. 1992;25:395-414.
23. Thelen DG, Schultz AB, Ashton-Miller JA. Co-contraction of lumbar muscles during the development of time-varying triaxial moments. *J Orthop Res*. 1995;13:390-398.
24. Zetterberg C, Andersson GB, Schultz AB. The activity of individual trunk muscles during heavy physical loading. *Spine*. 1987;12:1035-1040.
25. Crisco JJ, Panjabi MM. Postural biomechanical stability and gross muscular architecture of the spine. In: Winters JM, Woo SL-Y, eds. *Multiple Muscle Systems: Biomechanics and Movement Organization*. New York, NY: Springer-Verlag; 1991.
26. Janevic J, Ashton-Miller JA, Schultz AB. Large compressive preloads decrease lumbar motion segment flexibility. *J Orthop Res*. 1991;9:228-236.
27. Cholewicki J, McGill SM. Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain. *Clin Biomech*. 1996;11:1-15.
28. Cholewicki J, Panjabi M, Khachatryan A. Stabilizing function of trunk flexor-extensor muscles around a neutral spine posture. *Spine*. 1997;22:2207-2212.

29. Thelen DG, Schultz AB, Ashton-Miller JA. Co-contraction of lumbar muscles during development of time-varying triaxial moments. *J Orthop Res*. 1995;13: 390-398.39.
30. Floyd WF, Silver PHS. Function of the erector spinae muscles in flexion of the trunk. *Lancet*. 1951;1:133-143.
31. Kaigle AM, Wessberg P, Hansson TH. Muscular and kinetic behavior of the lumbar spine during flexion-extension. *J Spinal Disord*. 1998;11:163-174.
32. Quint U, Wilke HJ, Shirazi-Adl A, Parnianpour M, Loeb F, Claes LE. Importance of the intersegmental trunk muscles for the stability of the lumbar spine. *Spine*. 1998;23:1937-1945.
33. Solomonow M, Zhou BH, Baratta RV, Lu Y, Harris M. Biomechanics of increased exposure to lumbar injury caused by cyclic loading: Part I. Loss of reflexive muscular stabilization. *Spine*. 1999;24:2426-2434.
34. Ng HW, Teo EC, Lee KK, Qiu TX. Finite element analysis of cervical spinal instability under physiological loading. *J Spin Disord Tech*. 2003;16:55-65.
35. Adams MA, Dolan P, Hutton WC. Diurnal variations in the stresses on the lumbar spine. *Spine*. 1987;12:130-137.
36. Botsford DJ, Esses SI, Ogilvie-Harris DJ. In vivo diurnal variations in intervertebral disc volume and morphology. *Spine*. 1994;19:935-940.
37. Dolan P, Benjamin E, Adams M. Diurnal changes in bending and compressive stresses acting on the lumbar spine. *J Bone Joint Surg*. 1993;75:22.
38. Dunlap R, Adams M, Hutton W. Disc space narrowing and the lumbar facet joint. *J Bone Joint Surg*. 1984;66:706-710.
39. Eklund J, Corlett E. Shrinkage as a measure of the effect of load on the spine. *Spine*. 1984;9:189-194.
40. Indahl A, Kaigle A, Reikeras O, Holm S. Interaction between porcine lumbar intervertebral disc, zygapophyseal joints, and paraspinous muscles. *Spine*. 1997;22:2834-2840.
41. Stubbs M, Harris M, Solomonow M, Zhou B, Lu Y, Baratta RV. Ligamento-muscular protective reflex in the lumbar spine of the feline. *J Electromyogr Kinesiol*. 1998;8:197-204.
42. Richardson C, Jull G, Hodges P, Hides J. *Therapeutic Exercise for Spinal Segmental Stabilization in Lower Back Pain*. New York, NY: Churchill Livingstone; 1998.
43. Jull G, Richardson C, Toppenberg R, Comerford M, Bui B. Toward a Measure of Active Muscle Control for Lumbar Stabilization. *Aust J Physiother*. 1993;39: 187-193.
44. Hodges PW. Is there a role for transversus abdominis in lumbo-pelvic stability? *Man Ther*. 1999;4:74-86.
45. Hodges PW, Richardson CA. Transversus abdominis and the superficial abdominal muscles are controlled independently in a postural task. *Neurosci Lett*. 1999;265(2):91-94.
46. Hodges PW, Richardson CA. Delayed postural contraction of transversus abdominis in low back pain associated with movement of the lower limb. *J Spinal Disord*. 1998;11:46-56.
47. Morgan FP, King T. Primary instability of lumbar vertebrae as a common cause of low back pain. *J Bone Joint Surg*. 1957;39:6-22.

chapter 3

Functional Anatomy of the Cervical Spine

The cervical spine has many of the functional anatomical characteristics of the lumbosacral spine but also has many differences. The cervical spine has 7 functional units rather than the usual 5 of the lumbosacral spine, and the upper 3 functional units are totally different. The cervical spine mainly supports the head, with all the specific neurologic functions of the head, and thus needs a greater range of motion than does the lumbar spine.

From the third cervical vertebra downward, the functional units are very similar to those in the lumbosacral spine in that they have vertebrae separated by a disk, posterior facets, pedicles, and transverse processes (Figure 3.1). The cervical canal contains the spinal cord, whereas in the lumbosacral region the canal contains the nerve roots of the cauda equina (Figure 3.2).[1,2]

The cervical spine forms a lordosis dependent on the immediately inferior aspect of the spine, which has a thoracic kyphosis and the lumbar lordosis all essentially dependent on the lumbosacral angle (Figure 3.3).

Evolution of the cervical lordosis is evident from the total spinal curvature in utero to a newborn elevating its head first and maintaining that lordosis upon achieving the fully erect posture (Figure 3.4).

Because the head is a heavy structure, it must be balanced in relationship to the center of gravity. However, with increased thoracic kyphosis, the head becomes anterior to the center of gravity, causing substantial muscular effort in its maintenance (Figure 3.5).

UPPER CERVICAL COMPLEX

The upper cervical vertebral complex consists of the occiput, the atlas (C1), and the axis (C2). This cervical segment has specific movements that differ from the remainder of the cervical sine. The occipito-atlas (C1) articulation allows flexion-extension upon the condyles of the occiput upon the articulations of the atlas bodies (Figure 3.6). As these joints are congruent they permit movement in a saggital plane—flexion-extension—and prevent lateral and rotatory movements (Figure 3.7). The atlas (C1) consists of 2 lateral

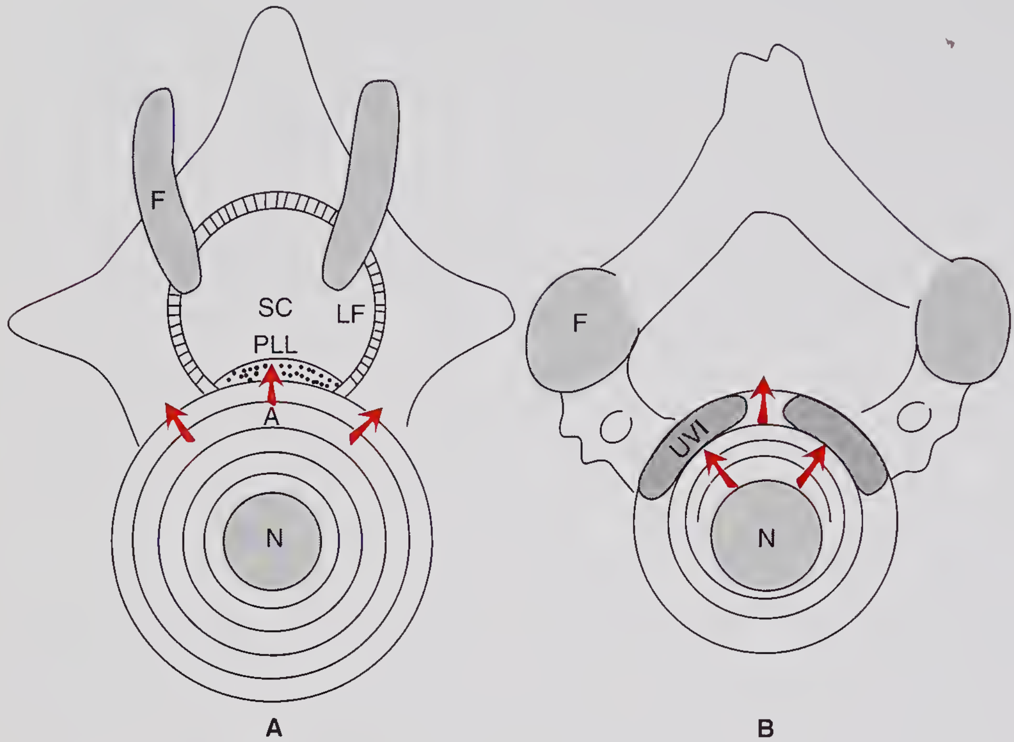


FIGURE 3.1

Typical Lower Cervical Vertebrae A, Typical cervical vertebra from C3 through C7. N indicates nucleus pulposus; A, annular fibers of disk; PLL, posterior longitudinal ligament; F, facets; SC, spinal canal; LF, ligamentum flavum. Arrows indicate direction of potential nuclear herniation. B, Uncovertebral joints (UVI), allegedly preventing disk herniation.

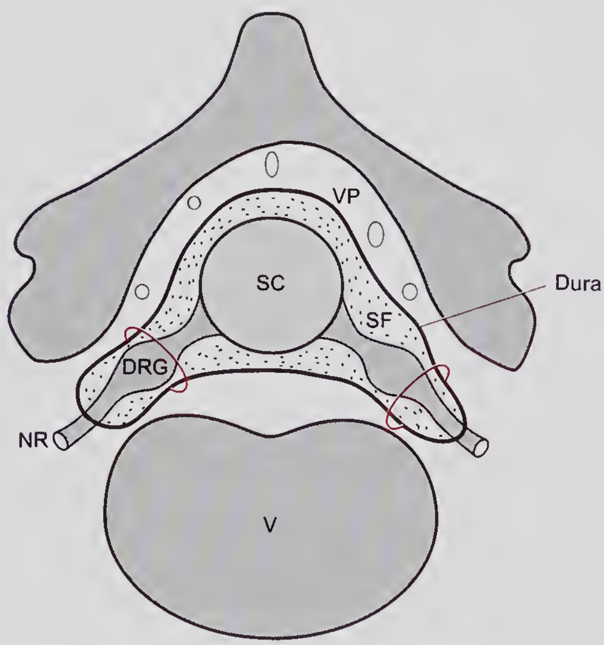


FIGURE 3.2

Dural Contents of Cervical Spinal Canal Spinal canal of cervical spine has spinal cord (SC) within its dural sheath, which contains spinal fluid (SF). Dura extends laterally into foramen, which contains dorsal root ganglion (DRG) extending into nerve root (NR)[3] Venous plexus (VP) drains epidural space. Canal changes its width during flexion-extension.[4] V indicates cervical vertebra from C3, viewed caudally.

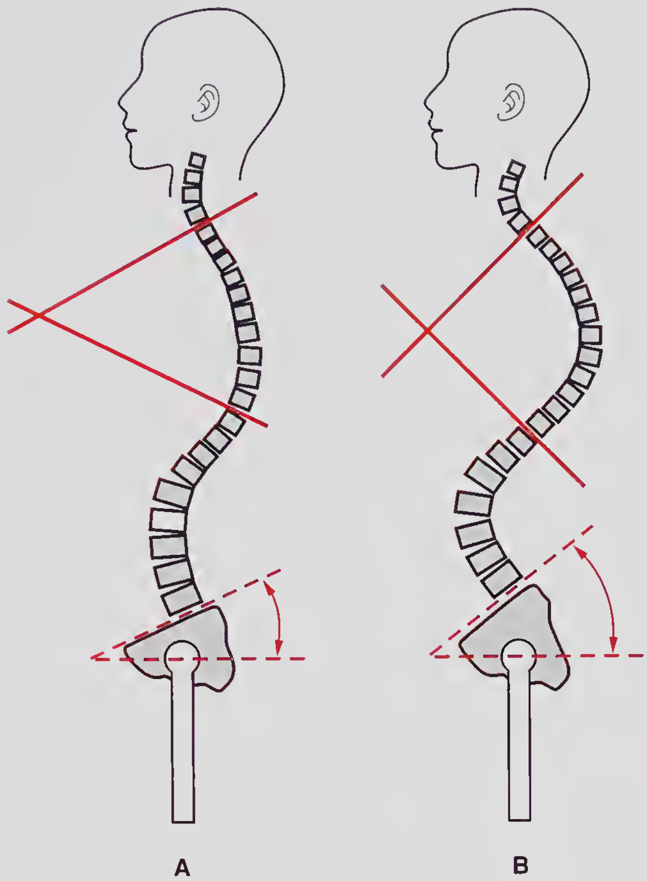


FIGURE 3.3

Spinal Curvatures Dependent on Sacral Angle Superincumbent spinal curves depend on the lumbosacral angle (dotted lines forming an angle of the pelvis). A, Minimal sacral angle with moderate curves of the lumbar, thoracic, and cervical curves. B, With greater sacral angle, all superincumbent curves are greater. Dark angles indicate the thoracic curves.

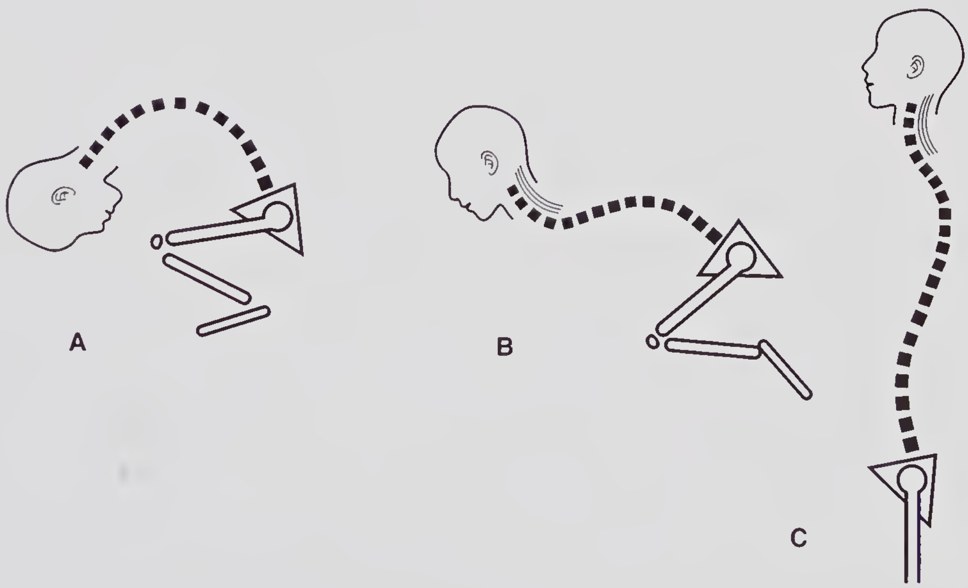


FIGURE 3.4

Evolution of Cervical Lordosis A, In utero posture is that of total flexion. B, Head is elevated early after birth, causing cervical lordotic posture. C, In erect adult posture, cervical lordotic posture persists.

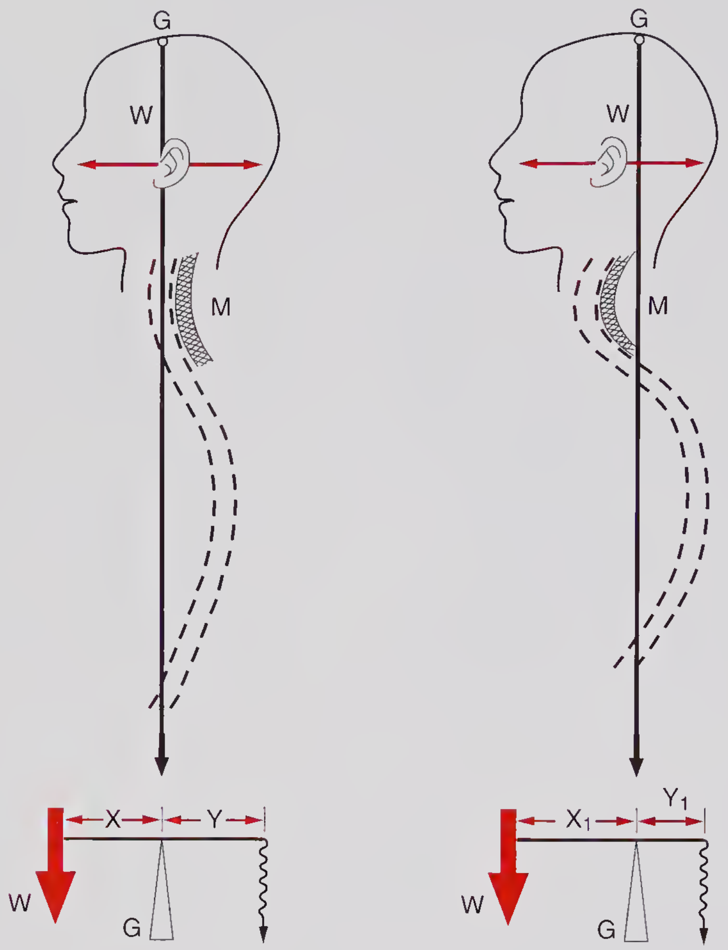


FIGURE 3.5

Cervical Support in Relationship to Center of Gravity Formula W × X = M × Y represents cervical support in relationship to center of gravity (G), where W is weight of head; X is distance of head from G; Y is distance of musculature from G; and M is muscular tension needed to support W. Simple lever system with fulcrum G is sum of weights acting at each end of lever bar. Any change in length of lever arm (from posture) influences formula.

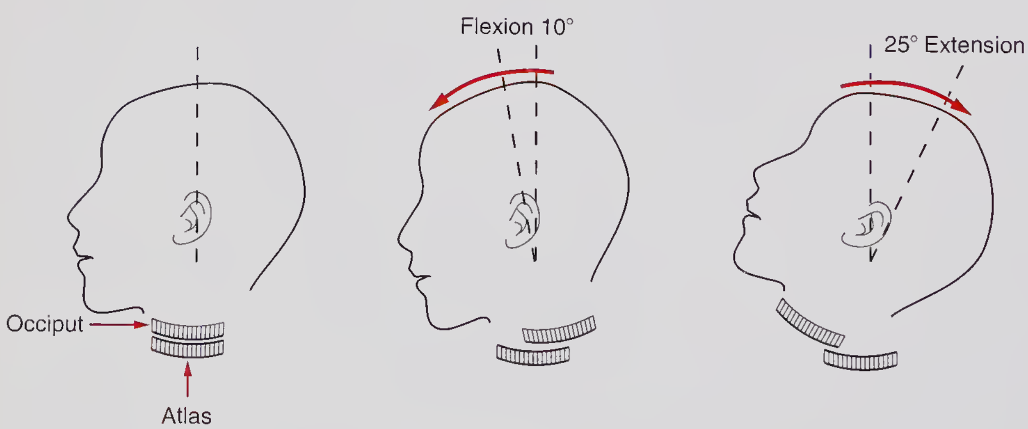


FIGURE 3.6

Occipital-Atlas Movement Convex surface of occipital condyles glide on superior concave joints of axis to allow flexion (10 degrees) and extension (25 degrees) for a total of 35 degrees of motion. No substantial lateral flexion or rotation is permitted.

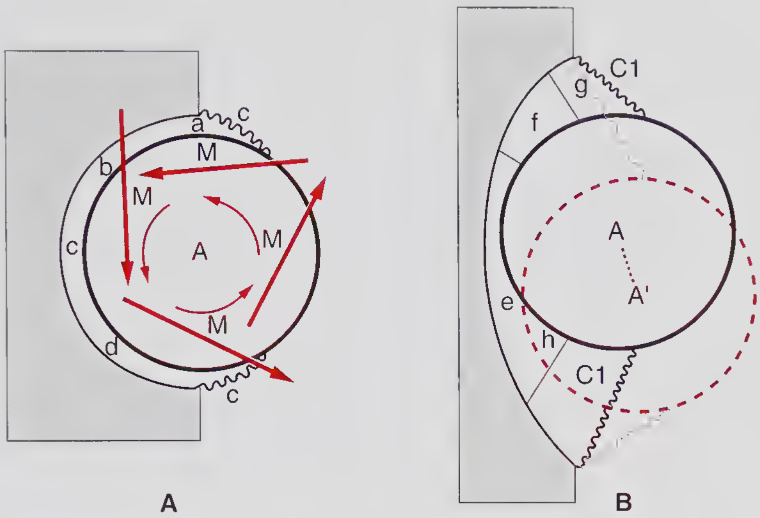


FIGURE 3.7

Congruency-Incongruence A, Congruent joint has both opposing surfaces and is totally symmetrical with equal space between opposing surfaces: a = b = c = d. Muscles (M) rotate joint about axis (A). B, Incongruous joint with concave and convex surfaces being of a different curvature; hence, movement is gliding rather than rotation. Axis changes: A-A. Capsules C and C1 show changes.

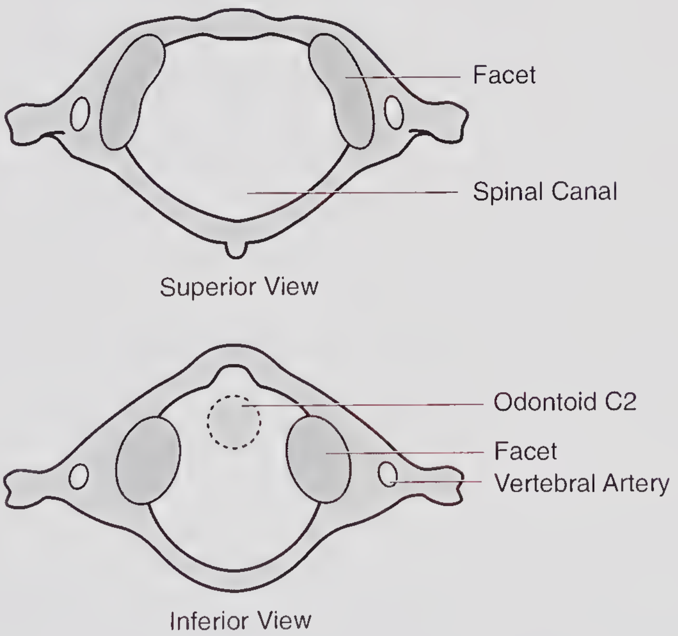


FIGURE 3.8

The Atlas Atlas is circular bone with facets at both lateral aspects. Superior facets are concave, and inferior aspect of facets is convex. Odontoid process of axis (C2 vertebra) is viewed here.

bodies connected by an anterior and posterior arch and not a central body, as evident in the vertebrae from C3 distally (Figure 3.8).

The occipital-atlas articulation allows motion in the sagittal plane, namely, flexion and extension. Flexion occurs to approximately 10 degrees and extends 25 degrees, for a total of 35 degrees. No substantial lateral flexion or rotation is permitted.

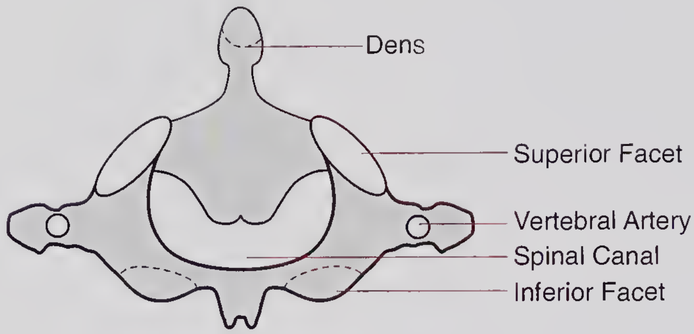


FIGURE 3.9

The Axis Axis (C2 vertebra) has superior facets that are concave to articulate on inferior facets of atlas. Inferior facets articulate on third cervical vertebra. Odontoid process ascends within spinal canal of atlas.

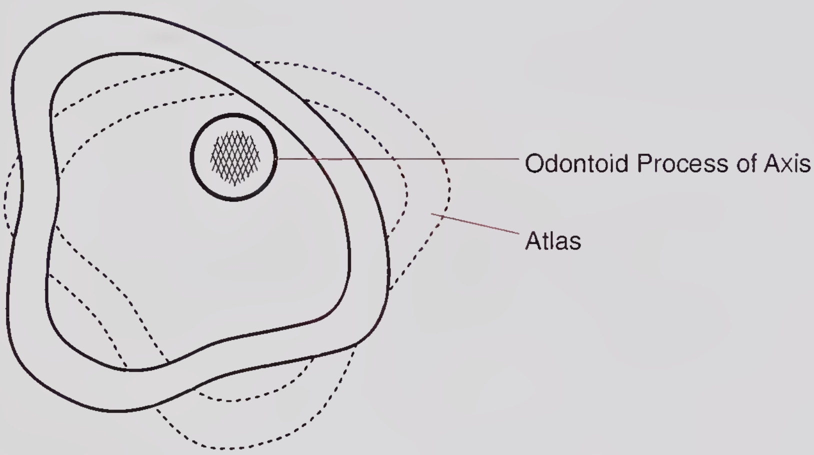


FIGURE 3.10

Rotation of Atlas on Axis Atlas rotates about odontoid process of axis 45 degrees in both directions for a total of 90 degrees.

The axis (C2 vertebra) is also a circular bone with superior and inferior facets that articulate with the atlas and on the third cervical vertebra (Figure 3.9). There are no intervertebral disks between the occiput and the atlas; rather, these joints are synarthrotic in that they have collagen-fibrous capsules.

The atlas does not have a central body, as do typical cervical vertebrae from C3 down; it has 2 lateral bodies that contain superior and inferior facet surfaces. The lateral bodies are connected by an anterior and a posterior arch. The anterior arch is thickened centrally, forming a body from which the odontoid process projects superiorly. The atlas rotates about the axis and therefore about the odontoid process, which resides anteriorly against the anterior arch (Figure 3.10). The lateral masses of the axis glide on the lateral masses of the atlas and inferiorly on the superior facets of the third cervical vertebra (Figure 3.11).

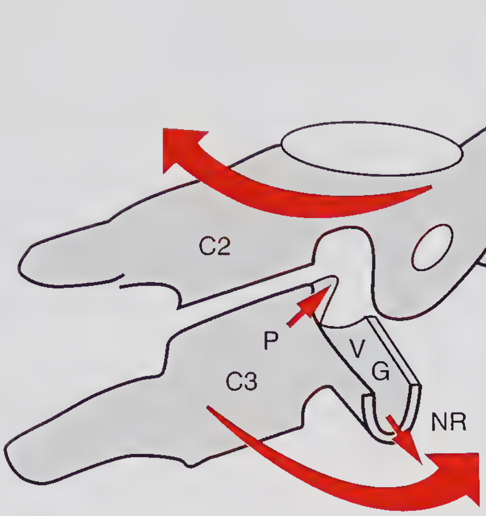


FIGURE 3.11

Rotation of C2 on C3 Axis (C2) rotates about third cervical vertebra and is mechanically limited. Anterior tip of upper articular process of C3 impinges on lateral margin of foramen of vertebral artery (V). Nerve root (NR) of C3 emerges through gutter (G). P indicates pedicle.

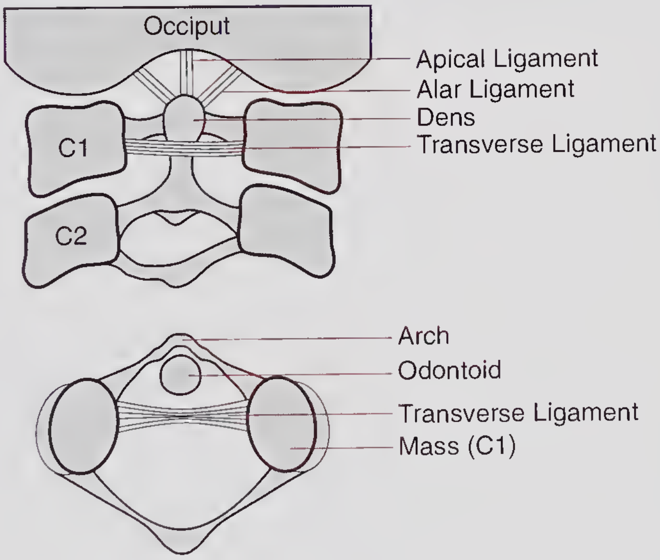


FIGURE 3.12

Occipital-Atlas-Axis Ligamentous Support Apical ligaments arise from tip of dens (odontoid process), attaching to foramen magnum of occiput. Transverse ligament contains dens within indenture on anterior arch of atlas.

Ligaments of the Occipital-Atlas-Axis Segment of the Cervical Spine

The ligaments of the atlantoaxial joints deserve specific attention, as they give these joints stability by limiting motion and protecting the spinal cord contained within the spinal canal. (Refer to Figure 3.1.)

The transverse ligament holds the odontoid process into the notch located posteriorly in the center of the anterior arch of the atlas (Figure 3.12).

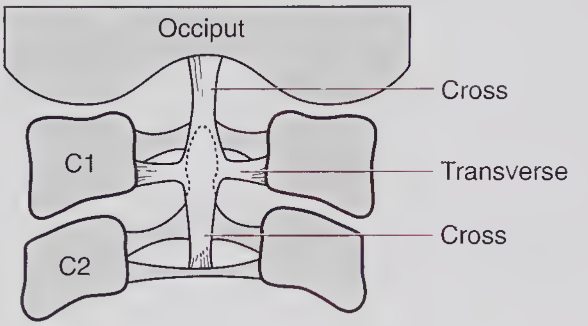


FIGURE 3.13

Transverse or Cross Ligaments At the midline the transverse ligament connects with the cross ligament that attaches from the occiput to the transverse ligament, connecting the 2 atlas vertebrae.

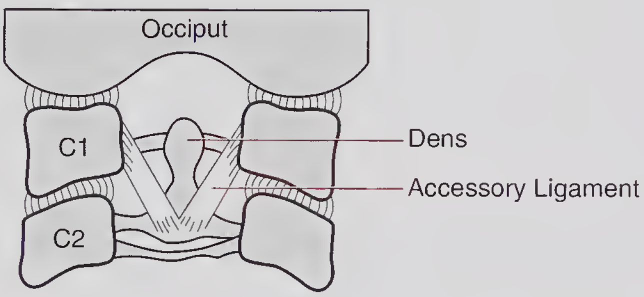


FIGURE 3.14

Accessory Atlantoaxial Ligaments These 2 ligaments attach from medial aspects of bodies of atlas and descend to converge on body of axis anterior to odontoid process (dens).

By holding the dens (odontoid process) there, this ligament ensures adequate space for the spinal cord within the canal. The alar ligaments limit rotation and lateral motion of the axis by their attachment on the tip of the dens.

The cross ligament is shaped as a cross, with the vertical positions attaching from the occiput to the posterior arch of the axis (Figure 3.13). It limits anterior posterior shear and some lateral motion.

The accessory atlantoaxial ligaments by their attachments limit the rotation of the atlas on the axis at their lateral bodies (Figure 3.14). Severance of one ligament allows rotation in one direction and restricts the other. The ligaments that attach to or from the dens limit motion and prevent subluxation into the spinal canal against the spinal cord (Figure 3.15).

There are also several major ligaments that extend from the foramen magnus caudally to attach to the sacrum. The major ligament is the posterior longitudinal ligament that originates at the occiput, where in its fanlike spread it is termed the *tectorial ligament*. This ligament protects the spinal cord within the spinal canal and limits excessive flexion (Figure 3.16).

The ligamentum flavum extends from the posterior arch of the atlas to the surface of the lamina of the axis. It descends through the entire vertebral column. It actually protects the spinal cord and with its attachment prevents subluxation of the vertebral components of the functional units.

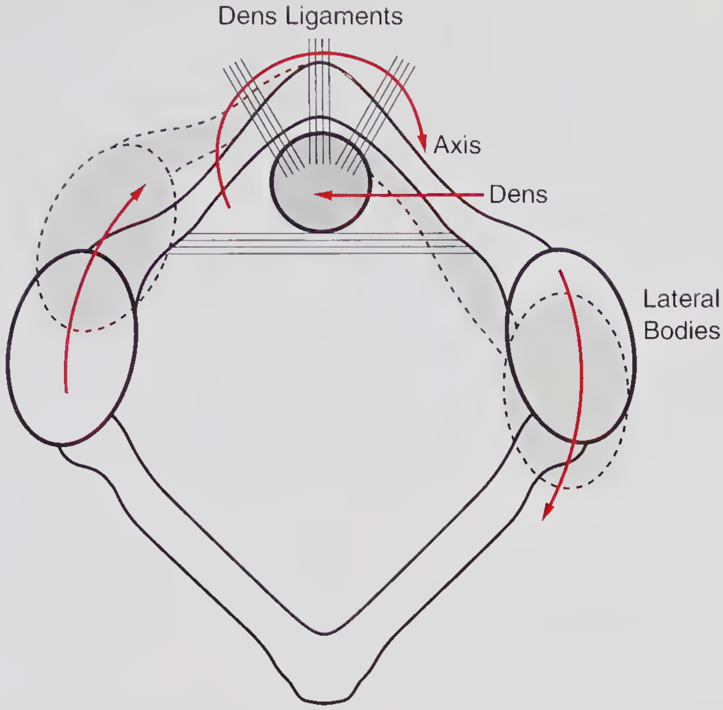


FIGURE 3.15

Rotational Motion of Atlas on Axis Rotation of approximately 45 degrees in either direction is allowed by translation of lateral bodies of atlas on axis and is limited by dens ligaments.

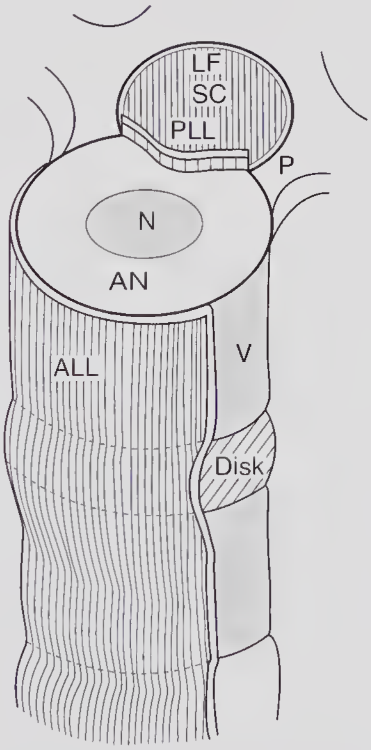


FIGURE 3.16

Long Ligaments Two vertebrae (V) shown indicate where the anterior longitudinal ligament (ALL) and posterior longitudinal ligament (PLL) attach. These ligaments extend entire length of vertebral column, attaching to vertebral bodies (V) and to intervertebral disk, where they bulge slightly physiologically. Also shown are disk nucleus (N) surrounded by annulus (AN) and spinal canal (SC) with posterior aspect of canal lined by ligamentum flavum (LF). P indicates pedicle.

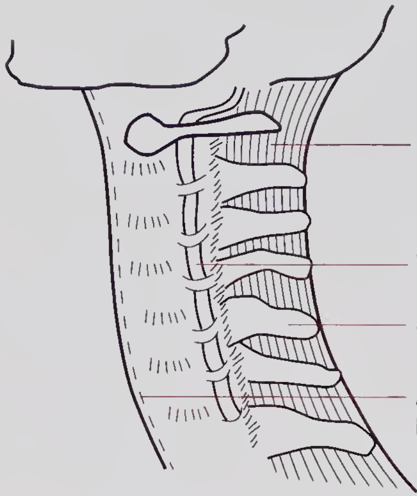


FIGURE 3.17

Ligamentum Nuchae This firm, essentially inelastic ligament attaches from base of skull and to each posterior superior spinous process.

The ligamentum nuchae is an interspinous ligament that extends from the occiput and attaches to each posterior spinous process as it descends. It reinforces the posterior aspect of the cervical spine and acts as a septum dividing the extensor muscles of the neck (Figure 3.17).

LOWER CERVICAL COMPLEX

Movement of the upper cervical spine—occiput, atlas, and axis—is both flexion-extension and rotation, but similar movement occurs in the lower cervical spine, C3–C7 (Figure 3.18).

Below the third cervical vertebra is situated the lower cervical complex, which consists of the C3 through C6 vertebrae. These comprise the more typical functional units noted in the remainder of the vertebral column: 2 adjacent vertebrae separated by a disk and posteriorly the pedicles, lamina, spinous processes, and foramina, through which emerge nerve roots contained within dural sacs. (Refer to Figures 3.1 and 3.2.)[4,5]

Because many of the structures in the cervical spine are potential nociceptive sites, these are enumerated in Figure 3.19.

The cervical vertebrae differ greatly from the lumbar vertebra. The cervical vertebrae have their disk nucleus more anterior, whereas the lumbar nuclei are central. The cervical vertebra have uncovertebral joints not found in the lumbar spine. The lumbar facets are sagittal, and the cervical facets are oblique and in a planar direction (Figure 3.20).

Uncovertebral Joint

The segmental structures of the lower cervical spinal vertebrae have a characteristic variation—the uncovertebral joint, also called the joint of Luschka—initially described by Herbert von Luschka[6,7,8] (Figure 3.21).

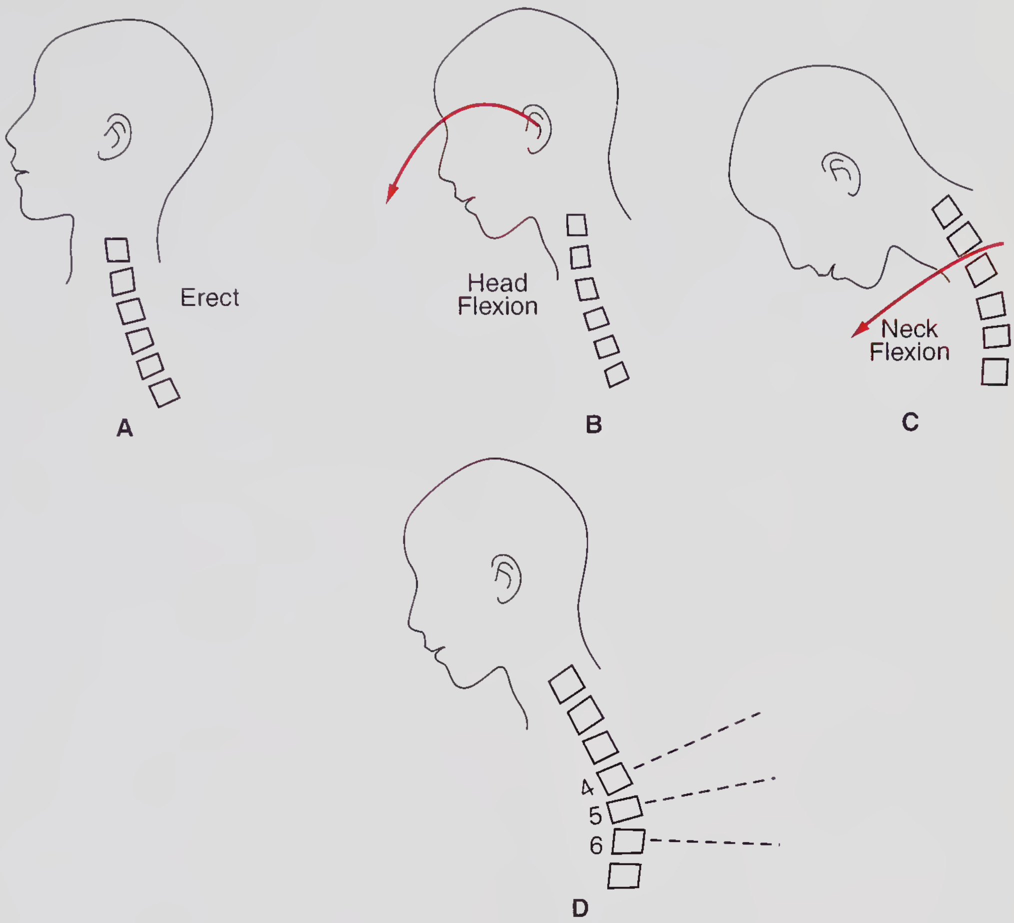


FIGURE 3.18

Movements of Cervical Spine A, Erect spine. B, Flexion of head on spine. C, Flexion of lower cervical spine. D, Cervical vertebrae where maximum flexion occurs.

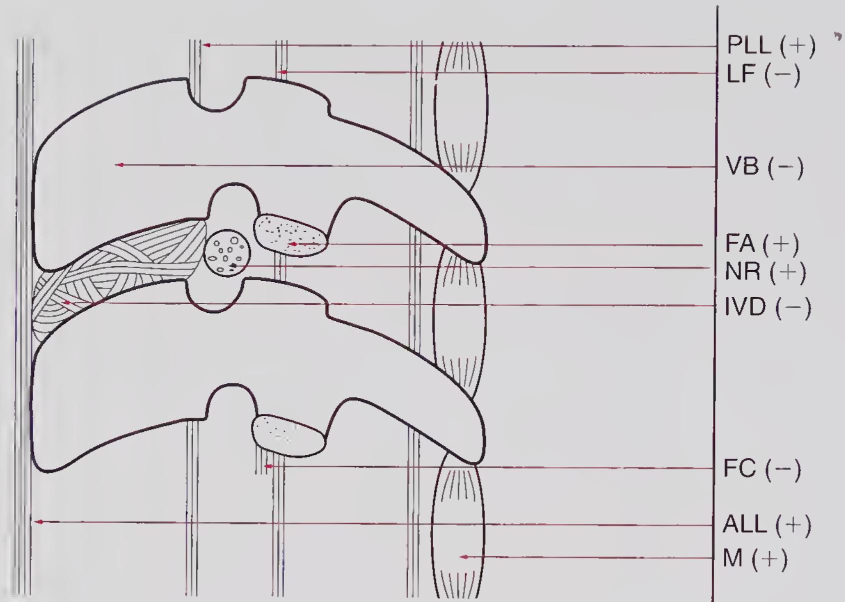
The processus articularis are covered by a thin layer of cartilage in healthy people, and the uneven surfaces between the zygapophyseal processes are filled by an infolding of the joint capsule, which is filled with connective tissue and fat called meniscoids. These meniscoids are highly vascular and well innervated. With aging, these meniscoids gradually disappear.[7]

In the first and second decades of life before complete ossification of the vertebral end plates, lateral tears occur in the disk annular fibers laterally. These tears tend to enlarge and migrate toward the medial (central) aspects of the disk, becoming transverse and literally dividing the disk in 2 parts by middle age. This gradually causes instability of the spine with migration of the nucleus toward the canal (Figure 3.22).

With gradual desiccation of the disk with aging and repetitive injuries, the disk narrows and no longer is weight-bearing, allowing the weight to be borne on the facets and the uncovertebral processes that hypertrophy.

The cervical spine, as in the lumbar spine, forms a lordotic curve in the erect posture, with each individual functional unit having a relative rotational angle (Figures 3.23, 3.24).

A



B

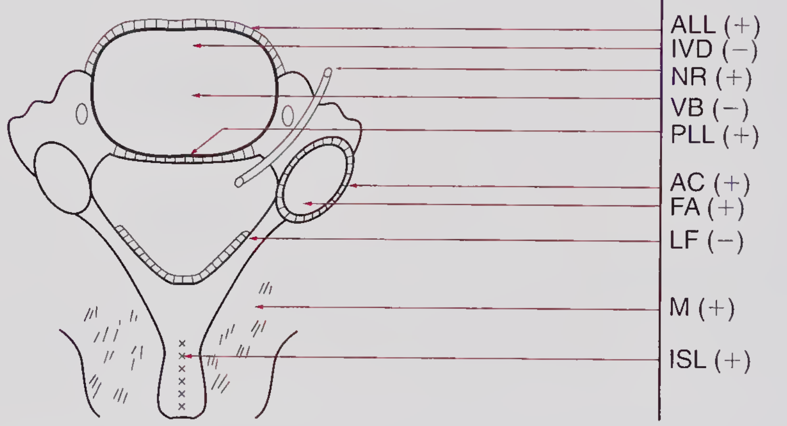


FIGURE 3.19

Cervical Functional Unit A, A lateral view of the cervical functional unit. VB indicates vertebral body; PLL, posterior longitudinal ligament; LF, ligamentum flavum; FA, inferior facet; NR, nerve root; IVD, intervertebral disc; ALL, anterior longitudinal ligament; M, erector muscles; FC, facet capsule. B, Figure A plus facet capsule (AC) and interspinous ligaments (ISL). The (+) indicate nociceptive qualities and (-) no sensitivity.

In the erect posture each vertebra supports the weight of the head in a tridimensional manner with weight-bearing being at the anterior vertebral disk aspect and some with bearing at the posterior facetal area (Figure 3.25).

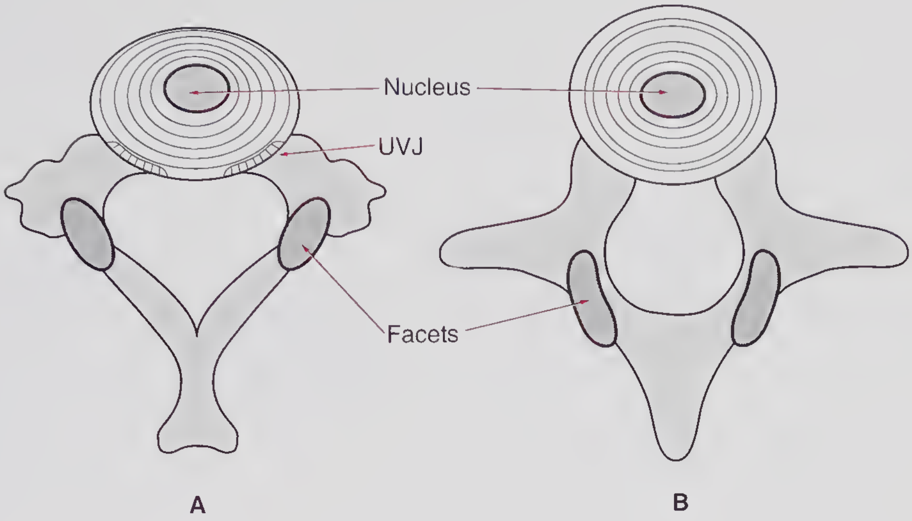


FIGURE 3.20

Nuclei of Disks in Lumbar and Cervical Vertebrae A, Cervical vertebra with anteriorly placed nucleus. B, Nucleus is centrally located. Uncovertebral joints (UVJ) are shown in cervical vertebra, whereas they are not present in lumbar vertebrae.

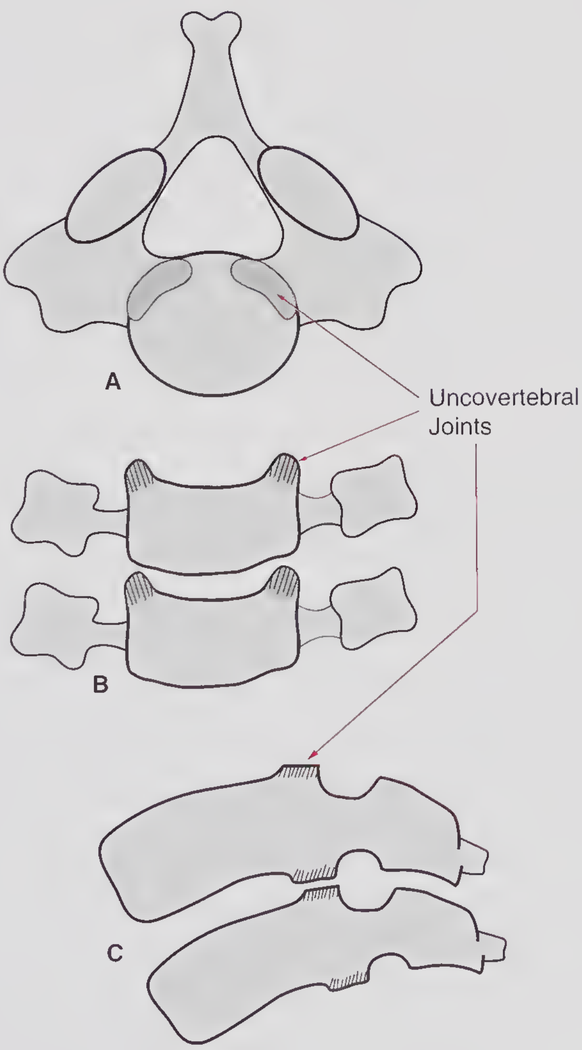


FIGURE 3.21

Uncovertebral Joints A, Uncovertebral joints (osseous protrusions) are present in posterior lateral areas of vertebra. B, View from front. C, View from side.

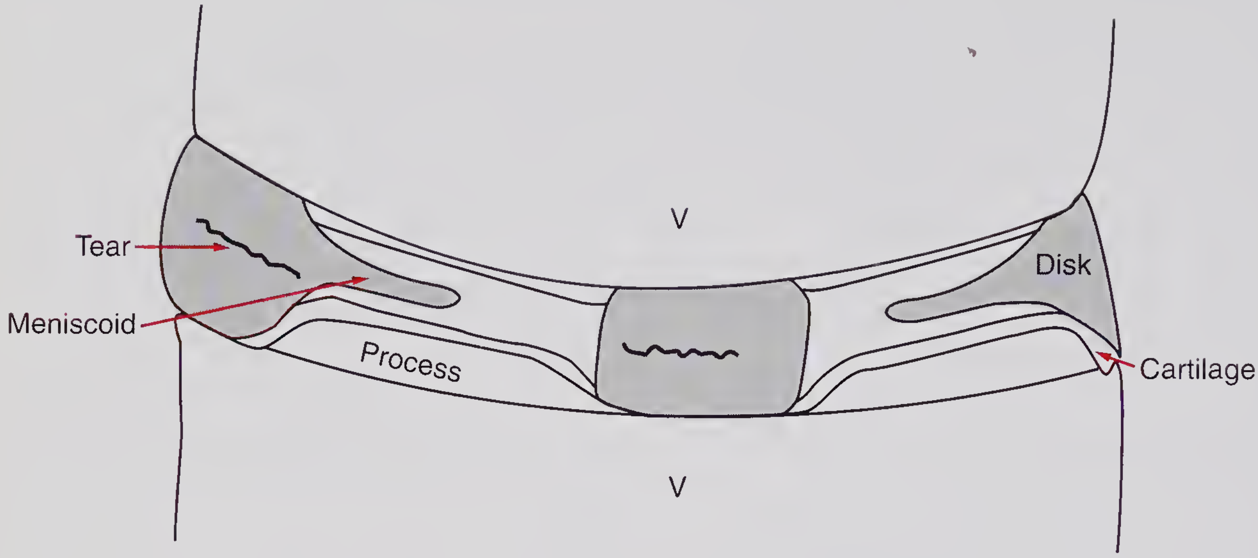


FIGURE 3.22

Uncovertebral Meniscoids Two adjacent vertebrae (V) of lower cervical spine show uncovertebral processes covered with cartilage. Capsule of joint of Luschka infold, forming meniscoid. Intervertebral disk gradually tears.

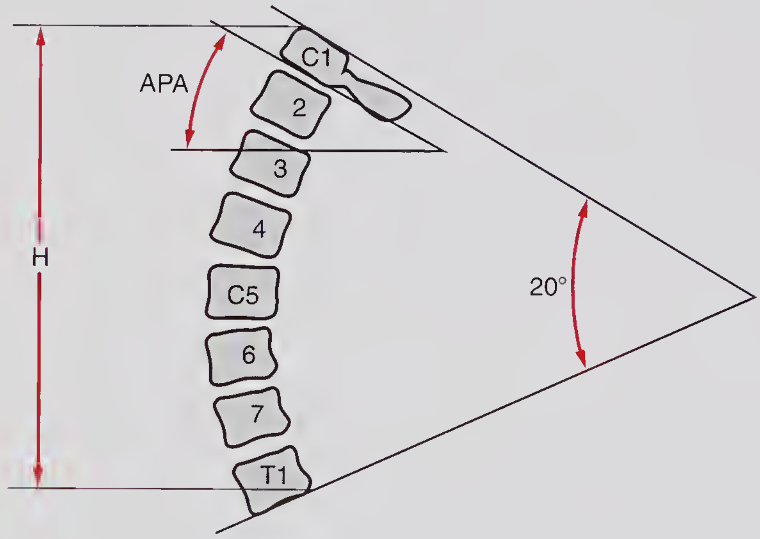


FIGURE 3.23

Rotational Angle of Cervical Lordosis Height of cervical spine (H) is determined by degree of curvature (lordosis) of spine from C2 through C7. Lordotic angle is in vicinity of 20 degrees. APA indicates angle of articular pillars of C1 vertebra.

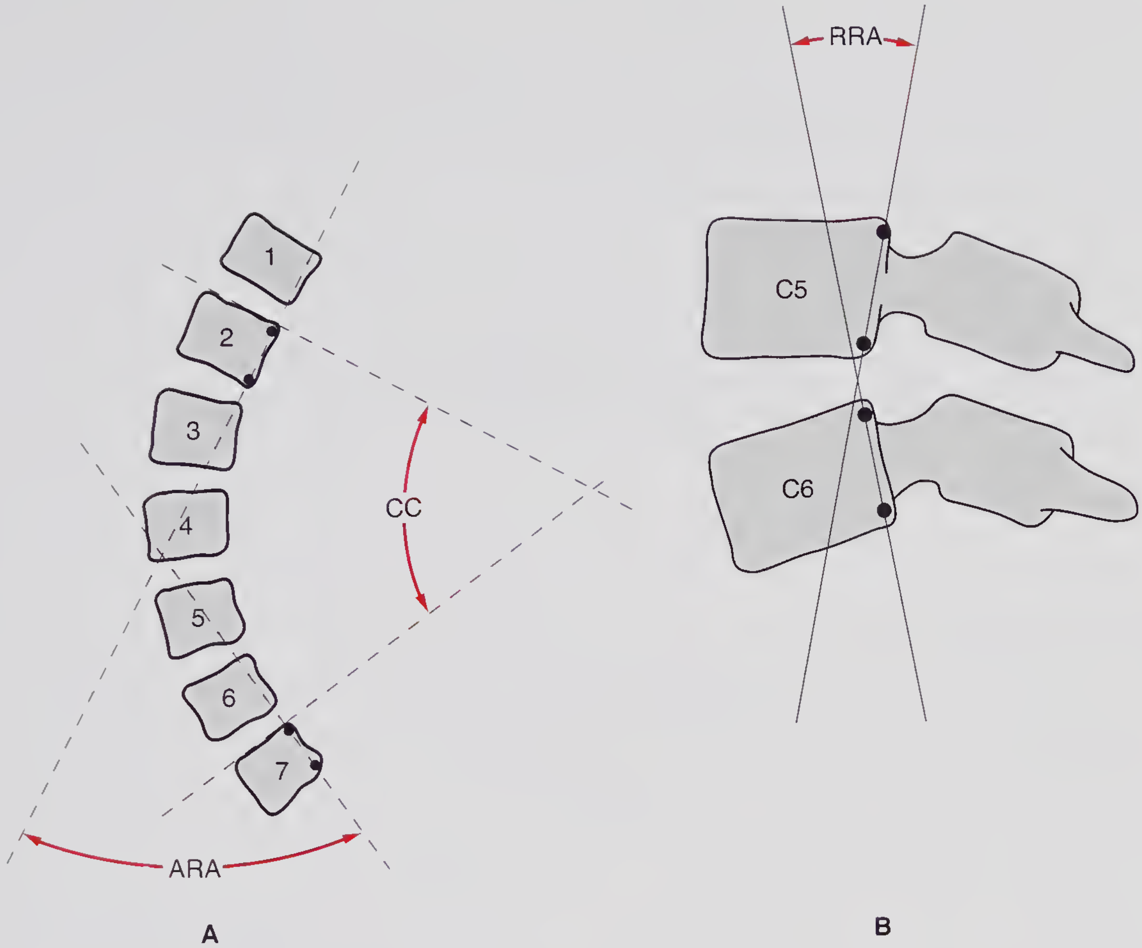


FIGURE 3.24

Cervical Lordosis at Individual Levels A, Cervical lordosis (CC) shows general curvature (ARA), as measured from line along superior margin of C2 and superior margin of C7. B, Two vertebrae, C5 and C6, show relative rotational angle (RRA).

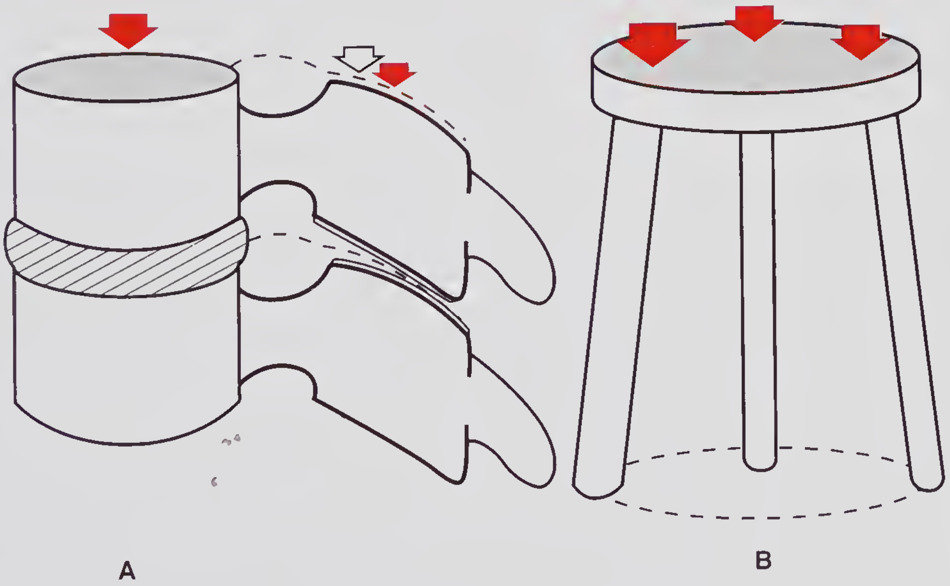


FIGURE 3.25

Weight-Bearing of Typical Cervical Vertebra A, Three-dimensional weight-bearing of cervical vertebrae. Large arrow indicates anterior portion—vertebrae and disk—bearing 50% of load; small arrows, zygapophyseal joints (facets), which share half the load (25% each). B, Example of 3-legged stool shows most weight borne on 1 leg (representing vertebra); other 2 legs are facets.

KINETIC CERVICAL SPINE

As the cervical spine flexes and reextends, there is a change in the lordosis to a kyphosis (Figure 3.26). Gliding of each functional unit depends on the angulation of the facets, which varies at the cervical level compared with the thoracic and lumbar levels (Figure 3.27).

Kinetic movement of the cervical spine is a conjoined movement, in which any lateral movement also includes rotation toward the ipsilateral side (Figure 3.28).

Limitation of motions of the cervical spine is dictated by the annular fibers of the intervertebral disks, the long ligaments, and the bony articular structures (Figure 3.29).

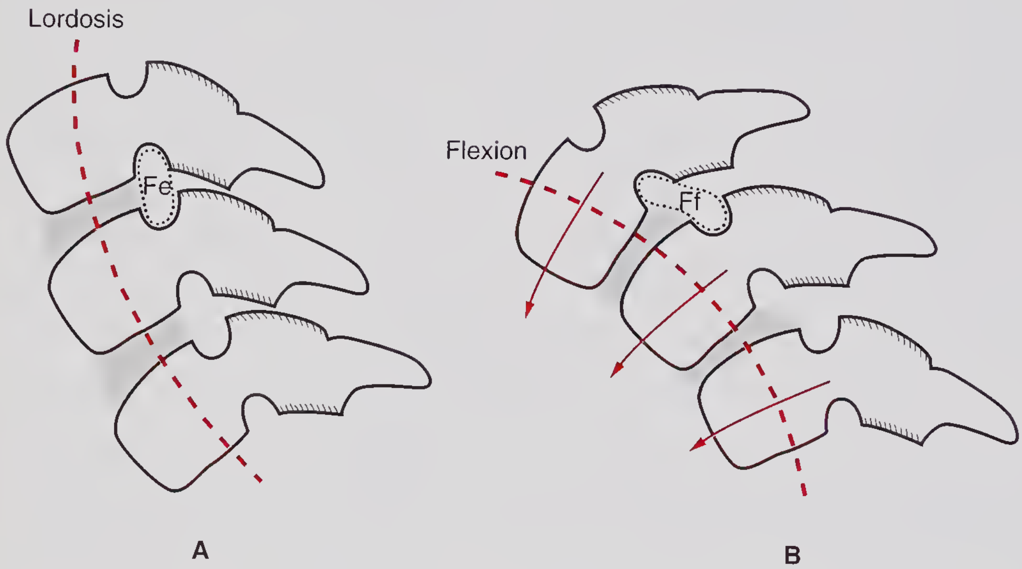


FIGURE 3.26

Flexion of Cervical Spine: Lower Segment A, Cervical lordosis and foramen size (Fe) are depicted. B, Flexion shows forward gliding of each vertebra (arrows) with deformation of disks, separation of facets, and opening of foramina (Ff).

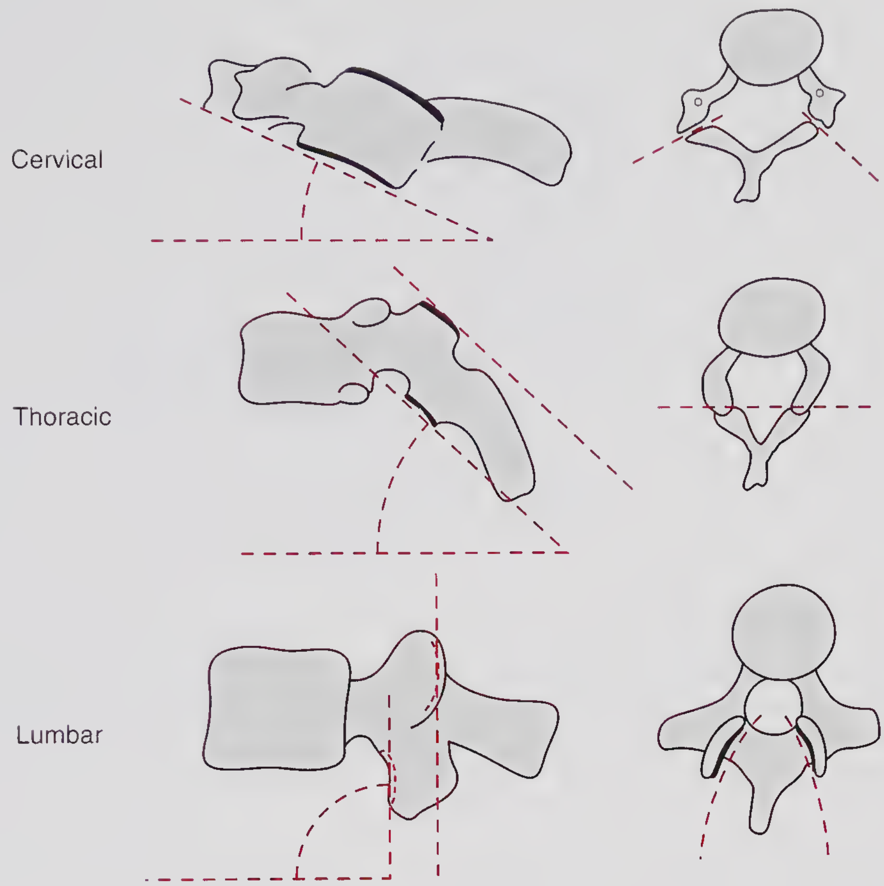


FIGURE 3.27

Levels of Facets in Each Segment of Spine Each angle of facet is depicted at cervical, thoracic, and lumbar levels.

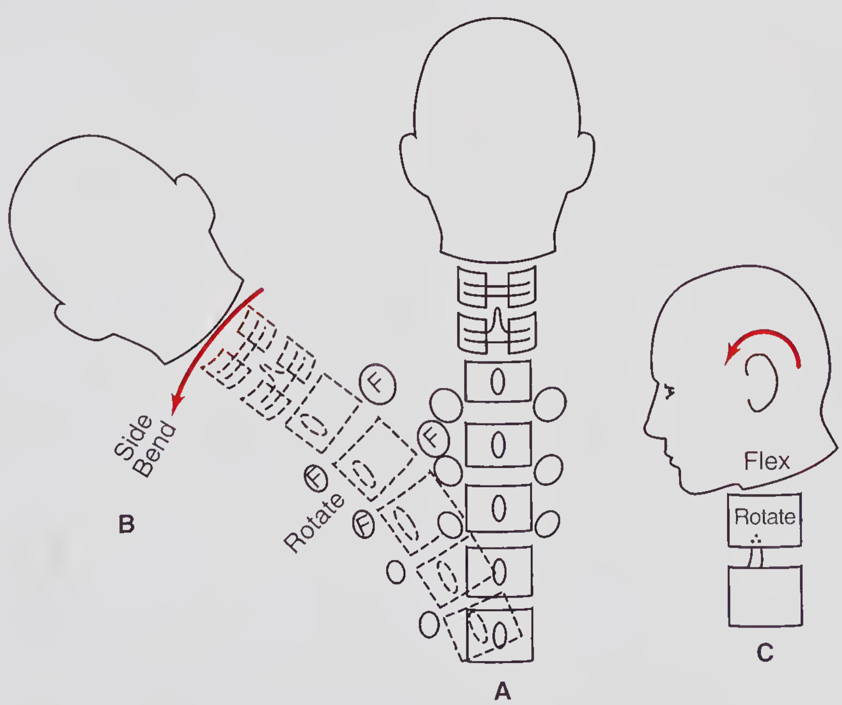


FIGURE 3.28

Conjoined Movement of Cervical Spine A, Erect spine with central circles being posterior superior spines and lateral circles being foramina. B, Left lateral flexion with simultaneous rotation of vertebrae. Foramina (F) on concave side narrow and on contralateral side open. C, Movement of occiput on atlas (C1) and rotation of atlas on axis (C2).

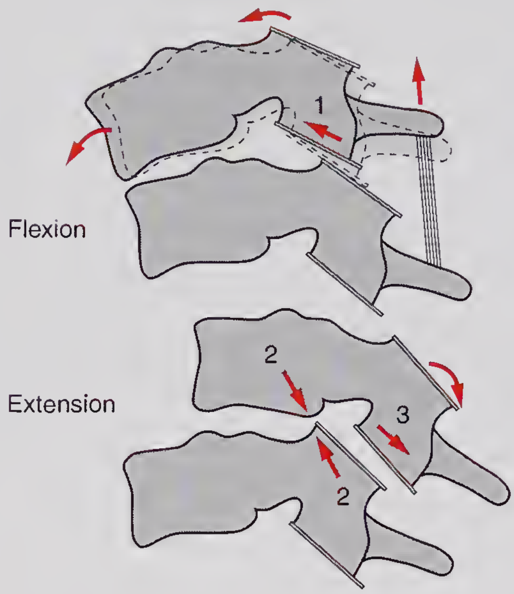


FIGURE 3.29

Mechanical Limitation of Lower Segment Cervical Vertebrae Flexion is limited by posterior ligaments and impingement of facets (1). In extension, inferior aspect of superior vertebra impinges on anterior aspect of superior facet (2), and capsule of facets also limits motion (3).

FUNCTION OF THE UNCINATE PROCESSES AND LUSCHKA JOINTS

The function of the uncinate joint processes and the Luschka joints has not been definitely clarified. The presence of the uncinate processes is assumed to reinforce the annular fibers and prevent the protrusion of the nucleus from moving posteriorly into the canal after nuclear herniation and encroaching on the spinal cord and nerve roots after pathology. This probably occurs, but the uncinate processes have a specific function in determining the degree of rotation in coupled movement of the lower cervical spine.[9] The uncinate processes are bony protuberances that extend cranially from the lateral margins of the superior end plates in the lower cervical spine.

Penning and Wilmink[9] hypothesized that the coupling motion is not determined solely by the orientation of the facets but suggested that the uncinate processes were involved. A fissure (cleft) running along the uncinate processes toward the nucleus pulposus creates what is called the Luschka joint, or uncovertebral joint (Figure 3.30).

This fissure, or cleft, appears in the posterior-lateral aspect of the disk. It appears in the latter aspect of the first decade of life and increases with aging. Originally considered a degenerative process, it is now considered to be a natural development that permits rotation of adjacent vertebrae in the lower cervical segment of the spine. Coupling of the elements of the cervical spine includes lateral flexion and simultaneous rotation.

The uncinate processes act as the axis of rotation. The increase in motion afforded by the presence of the cleft in the disk is countered by

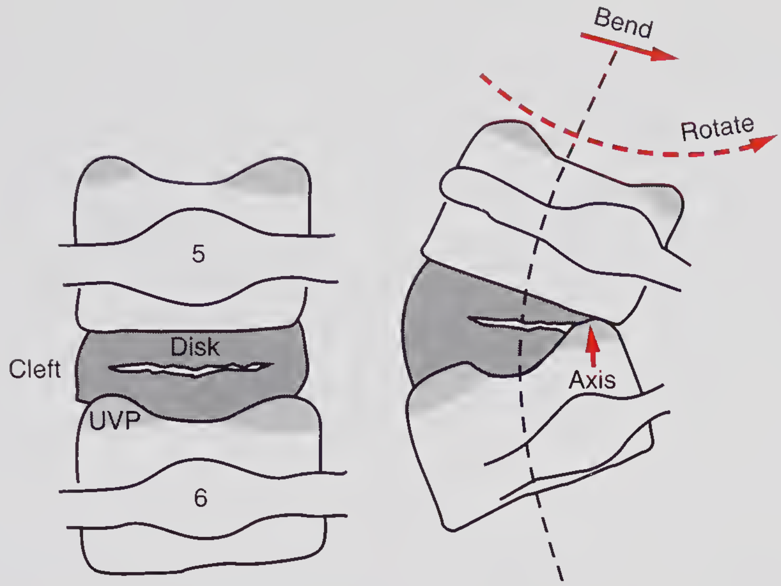


FIGURE 3.30

Coupling Rotation and Lateral Flexion of Cervical Spine When cervical spine flexes, laterally bends, and rotates (coupling action), uncovertebral processes (UVP) become axis of rotation, and cleft in disk allows rotation and lateral flexion.

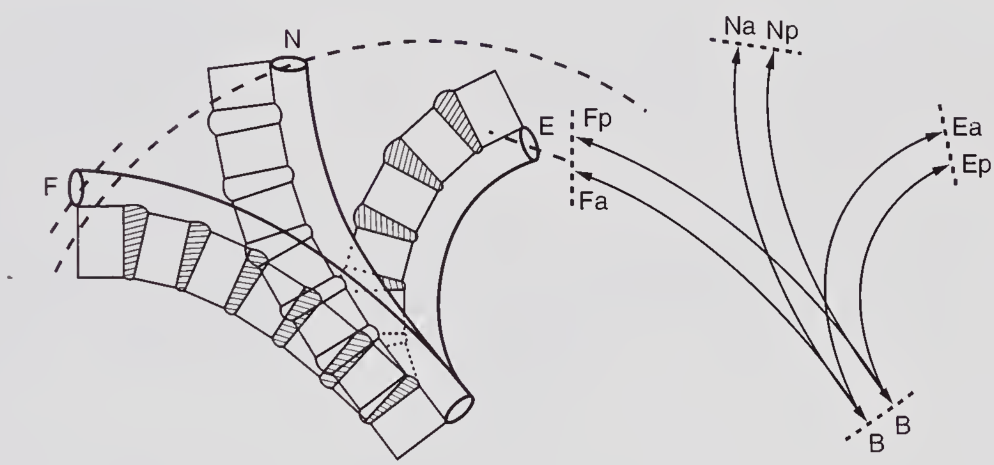


FIGURE 3.31

Variance in Spinal Canal Length In neural position (N) the length of the spinal canal is Na (anterior) and Np (posterior) to B with the former longer than the latter. In flexion the total length increases with the posterior layer (Fp) longer than the anterior (Fa). In extension the entire canal shortens, especially the posterior (Ep) over the anterior (Ea).

the degree of lateral flexion imposed by the uncinate processes that impinge on lateral flexion.

The length of the spinal canal also varies with flexion and extension. In flexion there is elongation and in extension there is a shortening. This will have a specific influence on the emerging nerve roots and the spinal cord dura (Figures 3.31, 3.32).

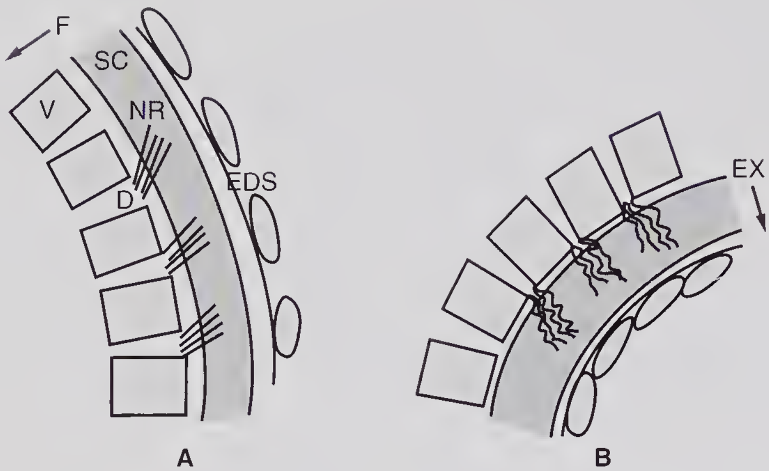


FIGURE 3.32

Nerve Root Change in Cervical Movement A, Cervical flexion (F) with elongation of spinal cord (SC) and angulation of nerve roots (NR). V indicates vertebra; D, disk; and EDS, extradural space. B, Extension (EX) with shortening of cord and minimal angulation of emerging nerve roots.

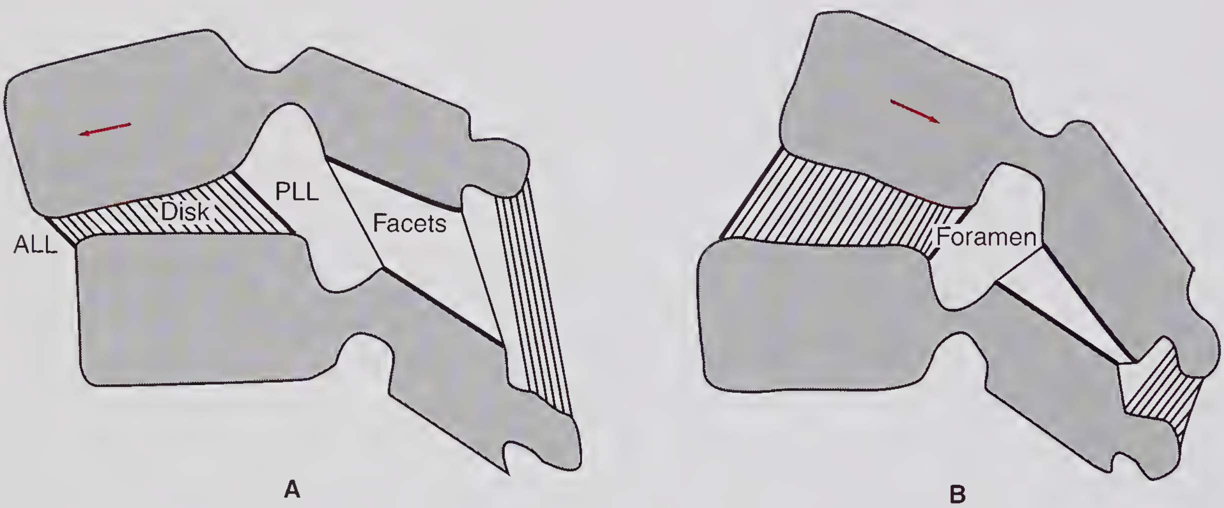


FIGURE 3.33

Movement of Foramen in Flexion and Extension A, Opening created by foramen on flexion (arrow). Anterior longitudinal ligament (ALL) shortens, and posterior longitudinal ligament (PLL) elongates. B, On extension, foramen (F) closes but, at this point, emerging nerve roots are horizontal.

The opening and closing of the foramen accommodate to the change of angulation of the emerging nerve roots. The foramen opens in flexion and closes on extension (Figures 3.33, 3.34).

Each nerve root is contained within a dural sheath containing spinal fluid (Figures 3.35, 3.36).

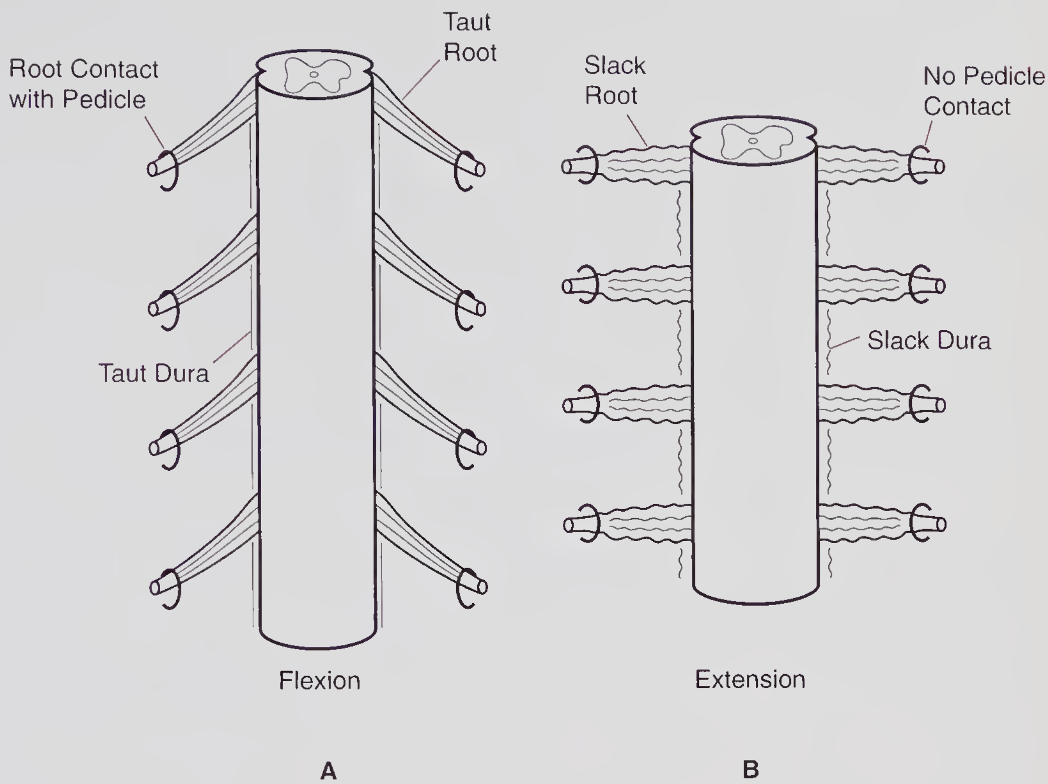


FIGURE 3.34

Nerve Root Angulation A, Angulation of emerging nerve roots on flexion, with minimal contact with foramen, which is open. B, Emergence at right angle of nerve root in extension.

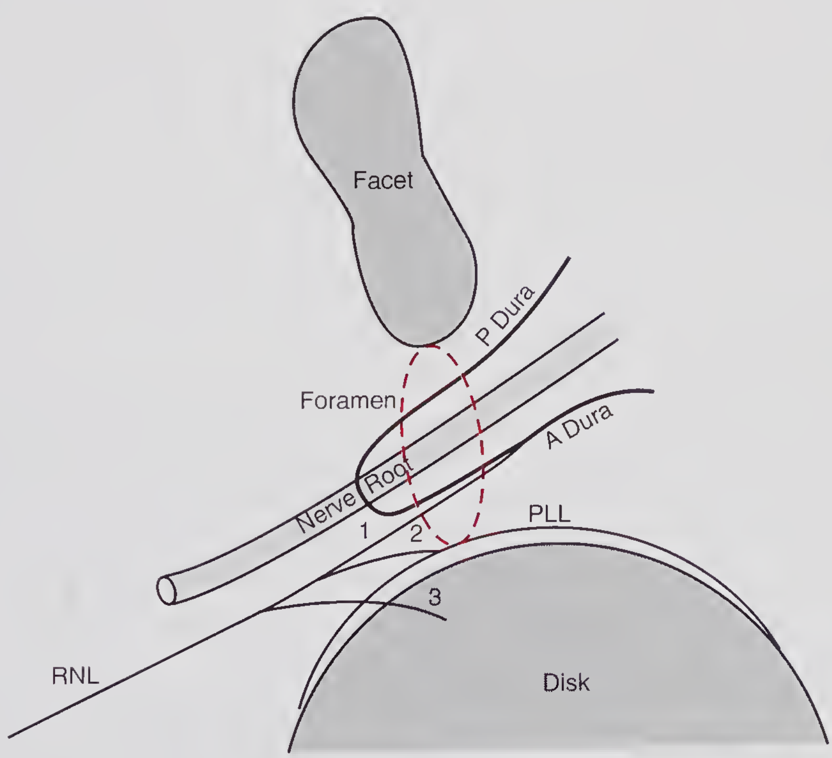


FIGURE 3.35

Structure of Nerve Root Each emerging nerve root from spinal cord through foramen is contained within posterior dural sleeve (P Dura) and anterior dural sleeve (A Dura). RNL indicates recurrent nerve of Luschka.

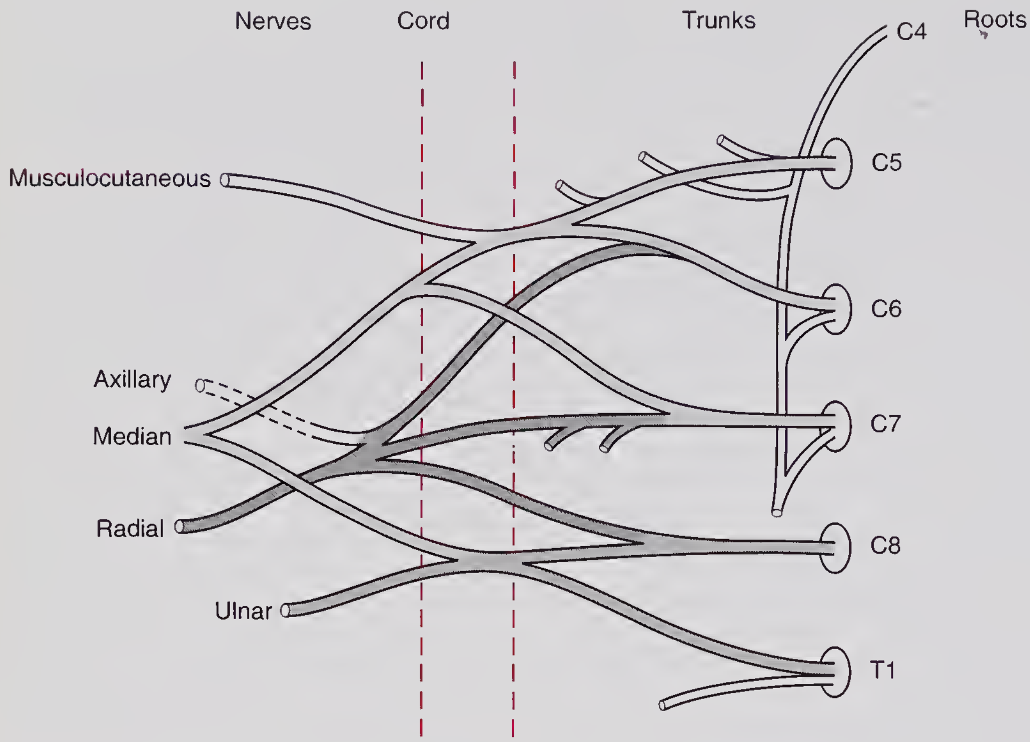


FIGURE 3.36

Components of Nerve Root Component structures of nerve root. Nerve roots emerge from individual foramen and merge to form trunks, cords, and ultimately individual peripheral nerves.

INNERVATION OF THE UPPER CERVICAL SEGMENT

The occipital nerves—greater and lesser—supply sensation of the posterior aspect of the cranium (Figure 3.37). The greater superior nerve emerges posteriorly from the occiput between the sites of origin of the trapezius and sternocleidomastoid muscles (Figure 3.38).

Clinically, if there is complaint of head pain and tenderness at the site of origin of the greater superior nerve, reproduction of the head pain confirms the origin of the pain. Relief is obtained by an analgesic injection into that nerve site. Pain referred from other nerves of the cervical spine originating from a specific foramen is tested by performing the Spurling test. In this test, the head of the patient is placed in slight extension and rotation to the affected side, and pressure is applied to the head. This maneuver closes the foramen on the concave side (Figure 3.39).

Production of cervical radiculopathy demands determining which foramen and which nerve root are implicated. The pain is referred to the dermatomic areas (Figure 3.40).

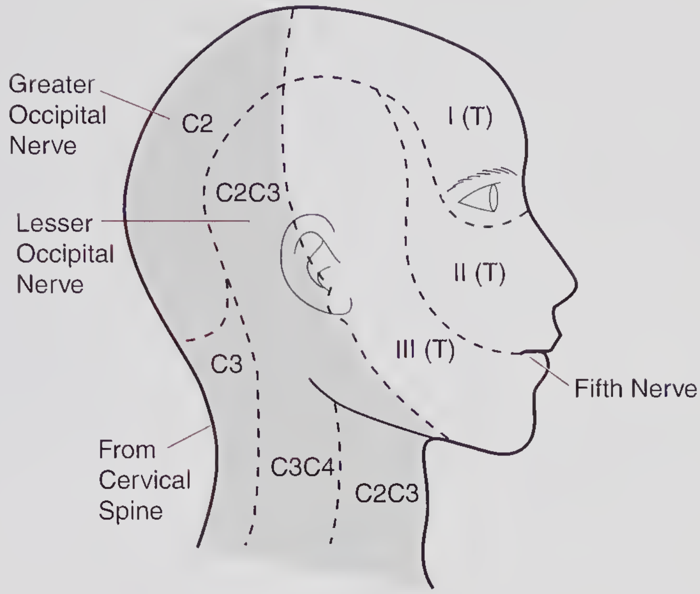


FIGURE 3.37

Dermatomic Areas of Occipital Nerves Dermatomic areas of occipital nerves are shown in relationship to dermatomic areas of trigeminal (fifth) nerve.

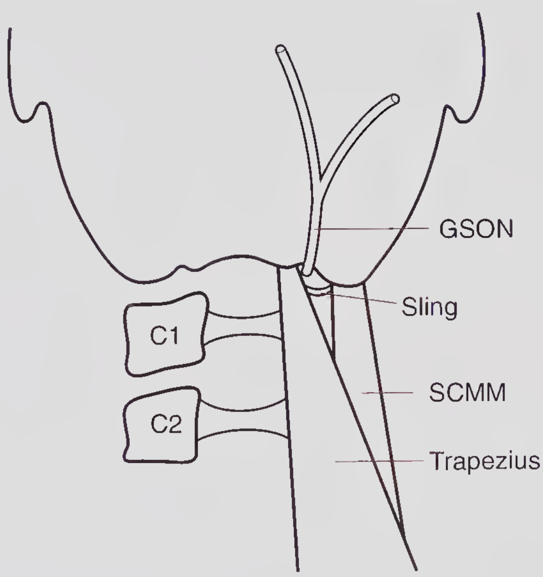


FIGURE 3.38

Emergence of Greater Superior Nerve Greater superior nerve (GSON) emerges from posterior occipital area through sulcus medial to mastoid process between origins of trapezius (TRAP) and sternocleidomastoid (SCMM) muscles. C1, C2, and C3 are vertebrae depicting site of origin of GSON.[2]

There are numerous causes of cervical radiculopathy ranging from rear-end vehicular accidents (whiplash-associated accidents) to postural daily activities, such as sitting at a computer (Figure 3.41).

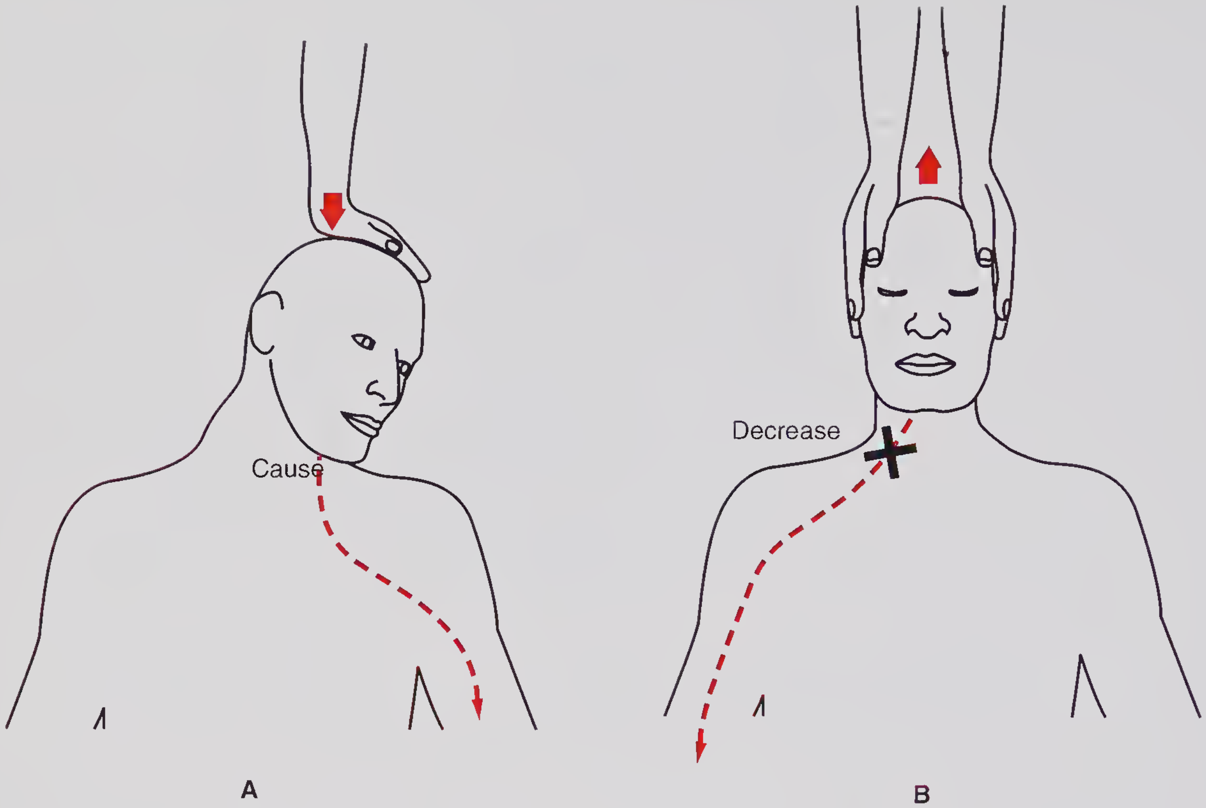


FIGURE 3.39

Spurling and Traction Tests A, Spurling test for cervical radiculopathy. B, Traction test, which opens foramen and relieves symptoms.

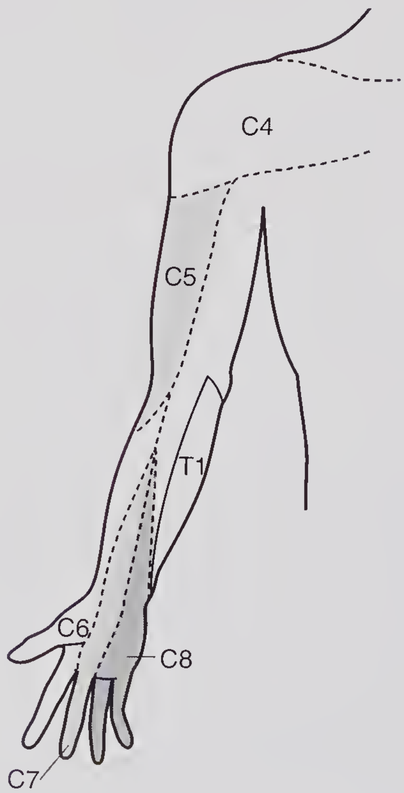


FIGURE 3.40

Dermatomic Areas of Upper Extremity Cervical dermatomic areas of upper extremity.

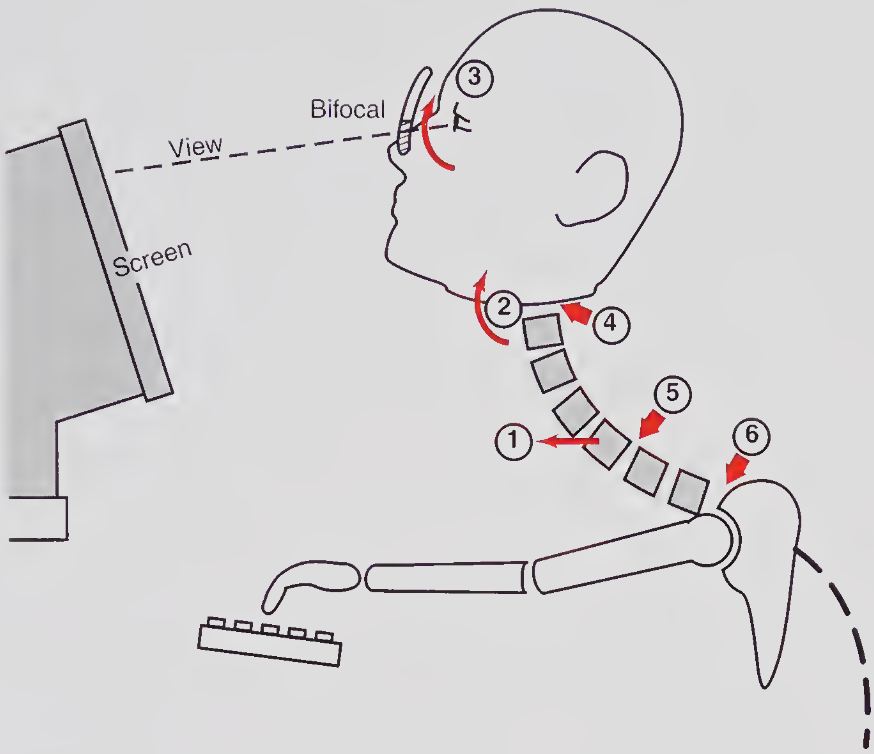


FIGURE 3.41

Postural Cervical Strain: Computer Posture In operating a computer, the head is held forward (1) causing the head to extend upon the spine (2). With bifocal glasses, the head extends further to view the screen via the lower aspect of the bifocals (3). Extending the head compresses the posterior tissues of the head-neck complex (4). With increase in cervical lordosis, the posterior facets compress (5). The arms held horizontal for long periods of time cause stress on the shoulder girdle (6).

MUSCULATURE OF THE CERVICAL SPINE

The muscles of the cervical spine can be functionally divided into 2 major groups: those that flex and extend the head on the upper cervical functional units and those that flex and extend the remaining lower cervical spine from the C3 to C7 vertebrae. The former are termed *capital movers* and the latter, *cervical movers* (Figure 3.42).[10]

The capital flexors are principally the short recti and longus capitis. The principal capital extensors are the 4 short muscles that extend from the base of the skull to attach to the atlas (C1) and axis (C2)—the posterior rectus capitis major and minor and the obliquus superior and inferior.

The longer muscles, splenius capitis and splenius cervicis, are primarily rotators of the head but extend the head when acting bilaterally. In addition, some muscles of the upper thoracic spine, including the trapezius and levator scapulae, extend, laterally flex, and rotate the cervical spine.

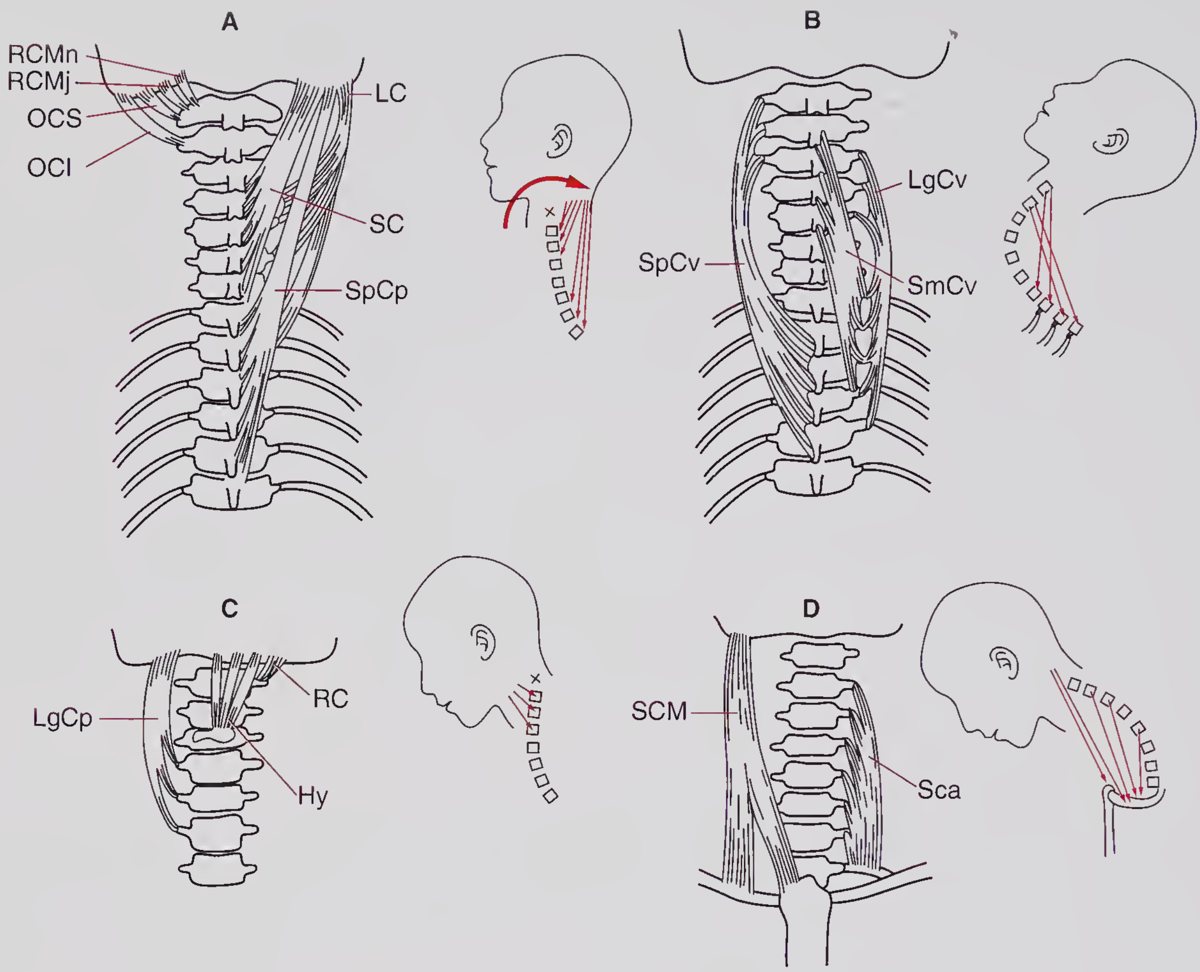


FIGURE 3.42

Musculature of Head and Neck A, Capital movers. Capital extensors attach to skull and extend head on cervical spine. B, Cervical movers. Cervical extensors originate from and attach to cervical spine. They alter cervical curvature. C, Capital flexors. D, Cervical flexors. RCMn indicates rectus capitis minor; RCMj, rectus capitis major; OCS, obliquus capitis superior; OCI, obliquus capitis inferior; LgCp, longus capitis; RC, rectus capitis anterior and lateral; Hy, hyoideus and suprahyoid muscles; LC, longissimus capitis; SC, semispinalis capitis; SpCp, splenius capitis; SpCv, splenius cervicis; LgCv, longissimus cervicis; SmCv, semispinalis cervicis; SCM, sternocleidomastoid; and Sca, scalenus medius and anticus.

REFERENCES

1. White AA, Panjabi MM. *Clinical Biomechanics of the Spine*. 2nd ed. Philadelphia, Pa: Lippincott Williams & Wilkins; 1990.
2. Hunter CR, Mayfield FH. Role of the upper cervical roots in the production of pain in the head. *Am J Surg*. 1949;78:743.
3. Bogduk N. The clinical anatomy of the cervical dorsal rami. *Spine*. 1982;7: 319-330.
4. Cailliet R. *Neck and Arm Pain*. 3rd ed. Philadelphia, Pa: FA Davis Co; 1991.
5. Cailliet R. *Soft Tissue Pain and Disability*. 3rd ed. Philadelphia, Pa: FA Davis Co; 1996.
6. von Luschka H. *Die Halbgelenke des menschlichen Koerpers*. Berlin, Germany: Reimers; 1858.

7. Penning L, Tondury G. Entshung, Bau und Funktion der meniskoiden Strukturen in den Halswirbelgelenken. *Z Orthop*. 1964:1-14.
8. Clausen JD, Goel VK, Traynelis VC, Seifert J. Uncinate processes and Luschka joints influence the biomechanics of the cervical spine: quantification using a finite element model of the C5-C6 segment. *J Orthop Res*. 1997;15:342-347.
9. Penning L, Wilmink JT. Rotation of the cervical spine: a CT study in normal subjects. *Spine*. 1987;12:732-738.
10. Winters, JD. Neck muscle activity and 3rd head kinematics during quasi-static and dynamic tracking movements. In: Winters JM, Woo SL-Y, eds. *Multiple Muscle Systems: Biomechanics and Movement Organization*. New York, NY: Springer-Verlag; 1991.

chapter 4

Functional Anatomy of the Shoulder

A comprehensive knowledge of the functional anatomy of the shoulder girdle and all of its component parts is mandatory in understanding arm-shoulder function. The basic function of the shoulder is to place the arm and especially the hand into a functional position that permits manipulative activities (Figure 4.1).

There is a complex neuromuscular pattern involved in the trajectory aspect of placing the hand and fingers where and how they function to accomplish the desired activity. This complex pattern involves numerous muscles for both the static and the kinetic aspects of shoulder function (Figure 4.2).

There are numerous joints in the shoulder complex that must be included in any functional activity of the upper extremity. All joints must be anatomically adequate, well controlled by muscular action, and have adequate sensory feedback (Figure 4.3).

SCAPULOCOSTAL JOINT

The shoulder blade, or the scapula, is the basic structure that supports the arm against the thoracic wall. The scapula is a flattened yet concave bone that articulates against the convex rib cage. It supports the upper extremity, involving the proximal articulation, the glenohumeral joint, which clinically implies the "shoulder joint."

In the dependent-arm position, the scapula is mechanically supported by ligamentous structures between the scapula and the clavicle (Figure 4.4). As the clavicle elevates when the arm is elevated, it would allow the scapula to rotate and elevate the glenoid fossa by only 30 degrees. However, by virtue of the clavicle being in a crank formation and because there is rotation of the clavicle at the sternal joint, the scapula elevates 60 degrees (Figures 4.5, 4.6).

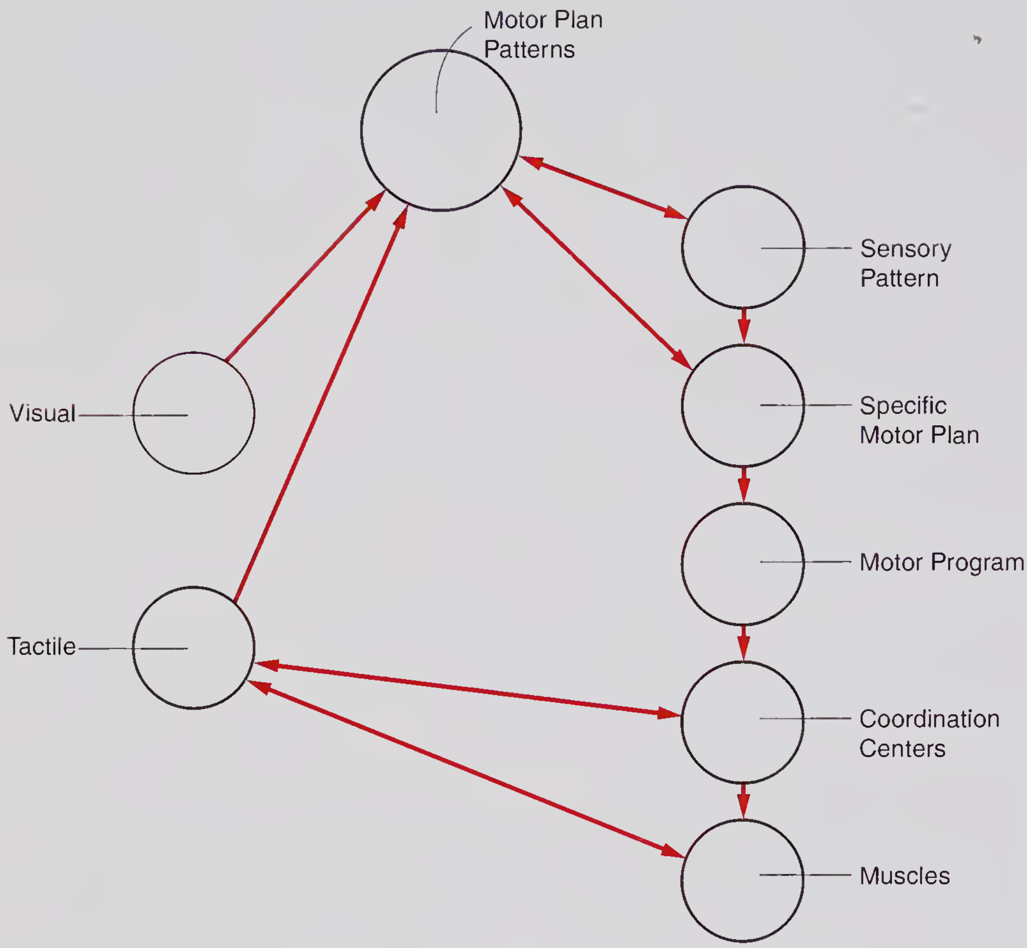


FIGURE 4.1

Functional Model of Hand Motor System General motor plan patterns in cerebral cortex and midbrain, especially cerebellum, initiates specific hand-finger pattern. Motor patterns exist in cortex and cerebellum along with sensory pattern. Motor patterns occur from hand muscles, which are coordinated by central and peripheral coordination centers, including visual and proprioceptive (tactile) responses.

The clavicle centrally rotates about the manubrium sterni, forming the sternoclavicular joint, where it has support on the first rib (Figures 4.7, 4.8).

The acromioclavicular joint at birth (0 to 2 years) is a fibrocartilaginous joint that gradually develops an intra-articular disk that permits motion of rotation, elevation, and descent (Figure 4.9).

Muscles Acting on the Scapula

There are numerous muscles attaching to and from the scapula that are involved in all arm and hand functions. Each merits discussion in interpreting total arm function (Figure 4.10).

The scapula is "held" against the chest wall with isometric muscular contraction supporting the arm. The major support muscles are the trapezius and the anterior serratus, which are also scapular rotators (Figure 4.11). The rhomboid muscles also rotate the scapula as well as act as supporters (Figure 4.12).

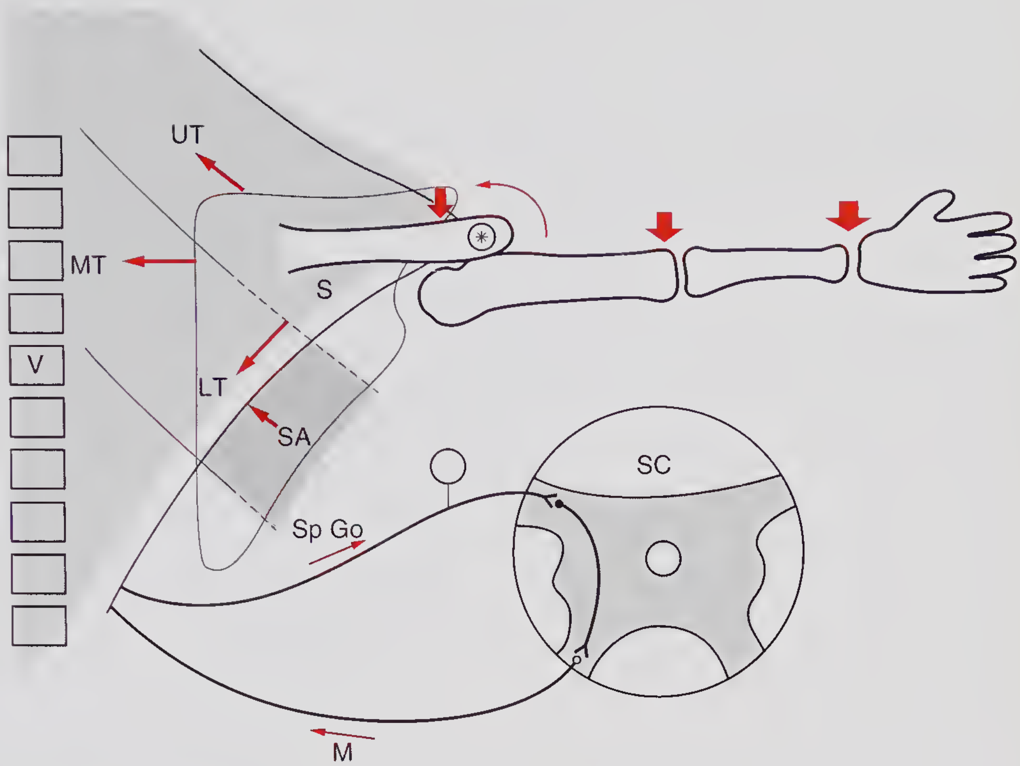


FIGURE 4.2

Complex Neuromuscular Trajectory of Upper Extremity In trajectory phase of upper extremity, when one places hand and fingers in their functional position, scapular muscles—upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and anterior serratus (SA)—sustain scapula (S) with isometric contraction to support upper extremity (large arrows). Weight depends on distance of object from scapula. All neuromuscular aspects are determined by spindle system (Sp) and Golgi (Go) apparatus "reporting" to spinal cord (SC), with resultant afferent impulses causing appropriate muscular (M) contraction. V indicates vertebra.

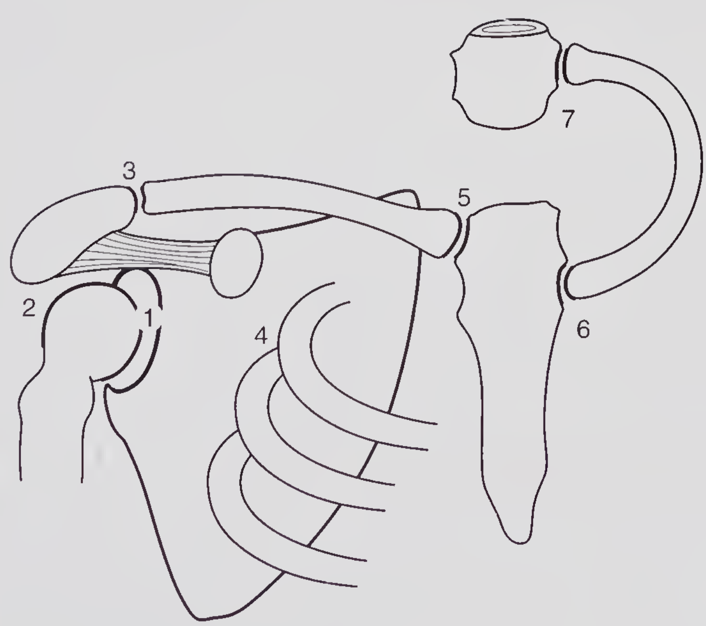


FIGURE 4.3

Joints of Shoulder Girdle Joints comprising shoulder girdle include glenohumeral (1), suprahumeral (2), acromioclavicular (3), scapulocostal (4), sternoclavicular (5), sternocostal (6), and costovertebral (7).

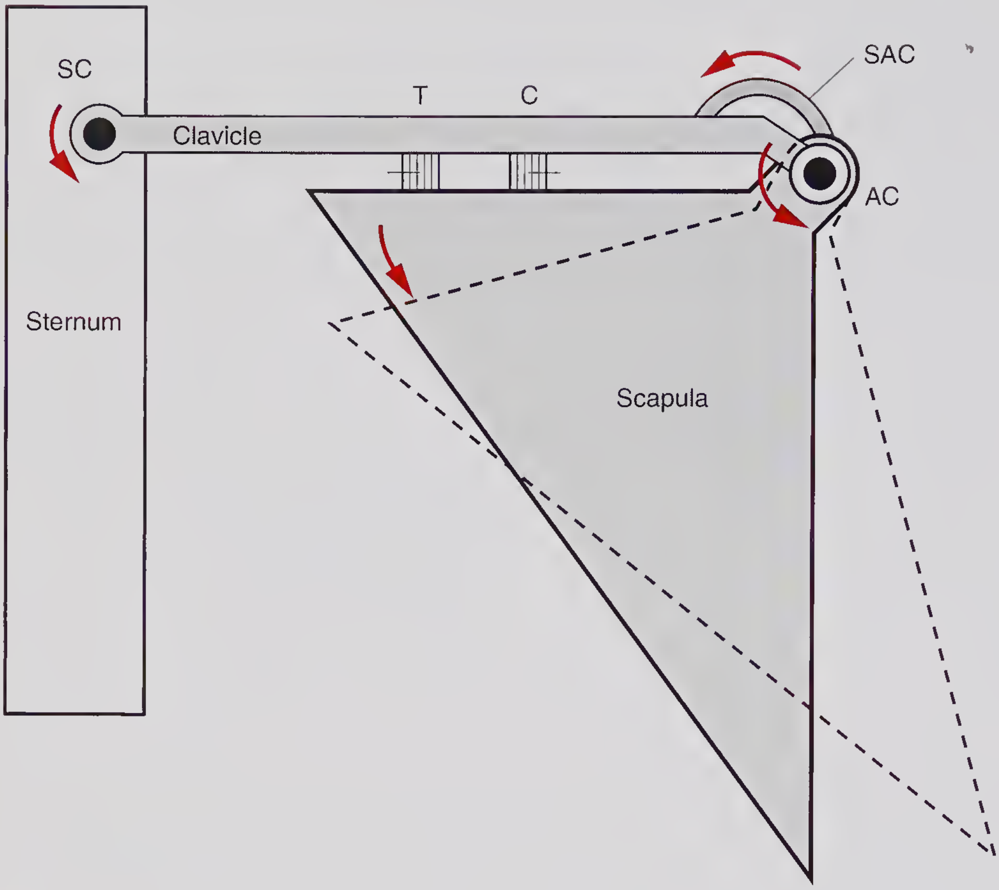


FIGURE 4.4

Static Support of Scapula by Claviculoscapular Ligaments Clavicle acts as a strut from sternum at sternoclavicular joint (SC). Scapula articulates on end of clavicle at acromioclavicular joint (AC). By its eccentric weight, scapula should mechanically rotate about this AC joint (dotted lines on scapula) except for restraint by claviculoscapular trapezium (T) and conoid (C) ligaments. Superior acromioclavicular ligament (SAC) assists and replaces support of other ligaments when they are severed by any trauma.

While the scapula statically maintains the upper extremity, it also functions in coordinated action with the remainder of the arm when the upper extremity performs its function or functions (Figure 4.13). One of its primary functions is to place the glenoid fossa and the acromion in their proper position during any movement of the humerus. The glenoid fossa is at the superior lateral aspect of the scapula under the acromion and lateral to the coracoid process. The glenoid fossa is a pear-shaped shallow depression, which is made deeper by a fibrous labrum that encircles the fossa (Figure 4.14). It normally faces up and out when the scapula is physiologically centered (Figure 4.15).

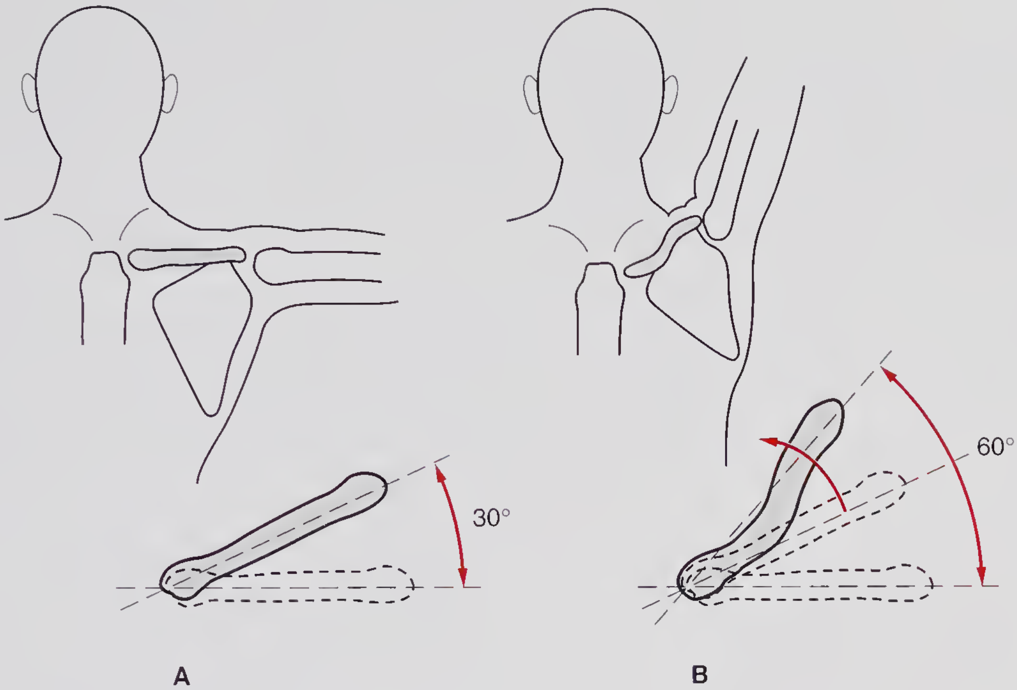


FIGURE 4.5

Rotation of Clavicle on Arm Overhead Elevation A, Without clavicular rotation about sternoclavicular joint, arm can elevate only 30 degrees. B, As there is rotation of clavicle, scapula elevates 60 degrees.

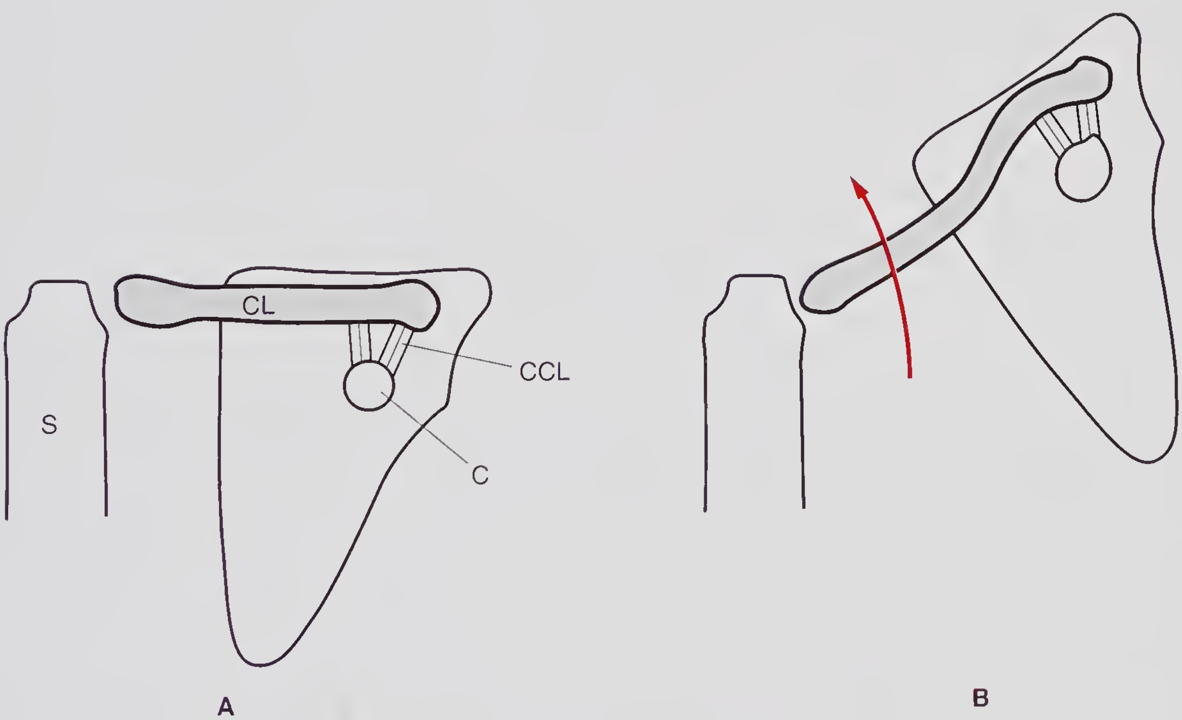


FIGURE 4.6

Effect of Clavicular Rotation on Conoid and Trapezoid Ligaments A, Coracoclavicular ligaments (CCL). C indicates coracoid process; CL, clavicle; S, sternum. B, Due to rotation of clavicle, coracoclavicular ligaments never are overstretched.

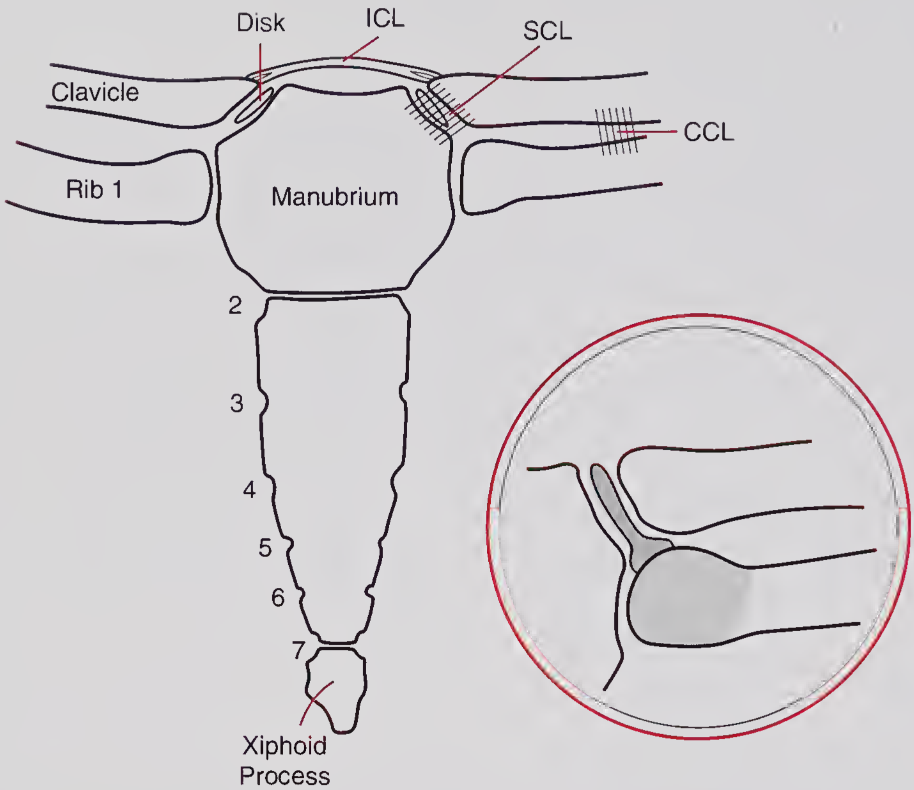


FIGURE 4.7

Sternoclavicular Joint Sternoclavicular joint is formed by medial portion of clavicle articulating on manubrium sterni and also with cartilaginous end of first rib. Interclavicular (ICL), sternoclavicular (SCL), and costoclavicular ligaments (CCL) stabilize joint. There is fibroelastic disk between medial clavicle and sternum (inset).

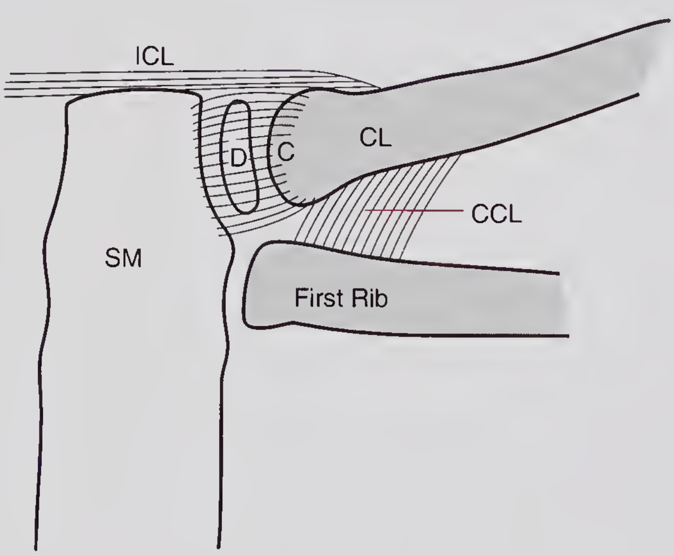


FIGURE 4.8

Ligaments of Sternoclavicular Joint Disk (D) between medial end of clavicle (CL) and sternum (SM) is supported by claviculocostal ligament (CCL), interclavicular ligament (ICL), and capsular ligaments (C).

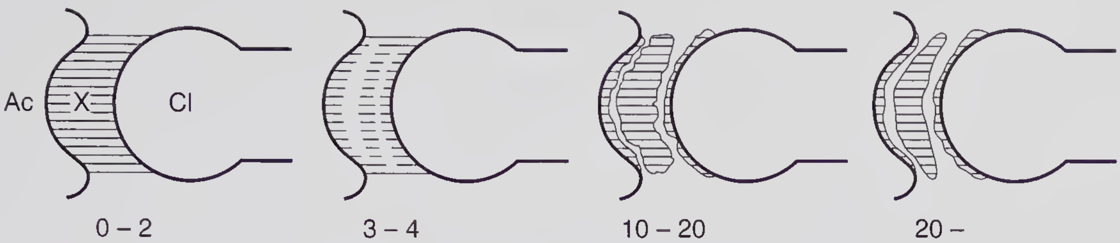


FIGURE 4.9

Evolution of Acromioclavicular Disk (Meniscus) From birth to age 2 years, acromioclavicular joint has a fibrocartilaginous bridge (X) connecting medial end of acromion (Ac) to lateral end of clavicle (Cl). From ages 3 to 4 years, cavities form on either side of what will become meniscus. These tears probably occur because of rotatory torque of this joint. In first to second decades of life, meniscus forms but gradually disappears from age 20 years and on.

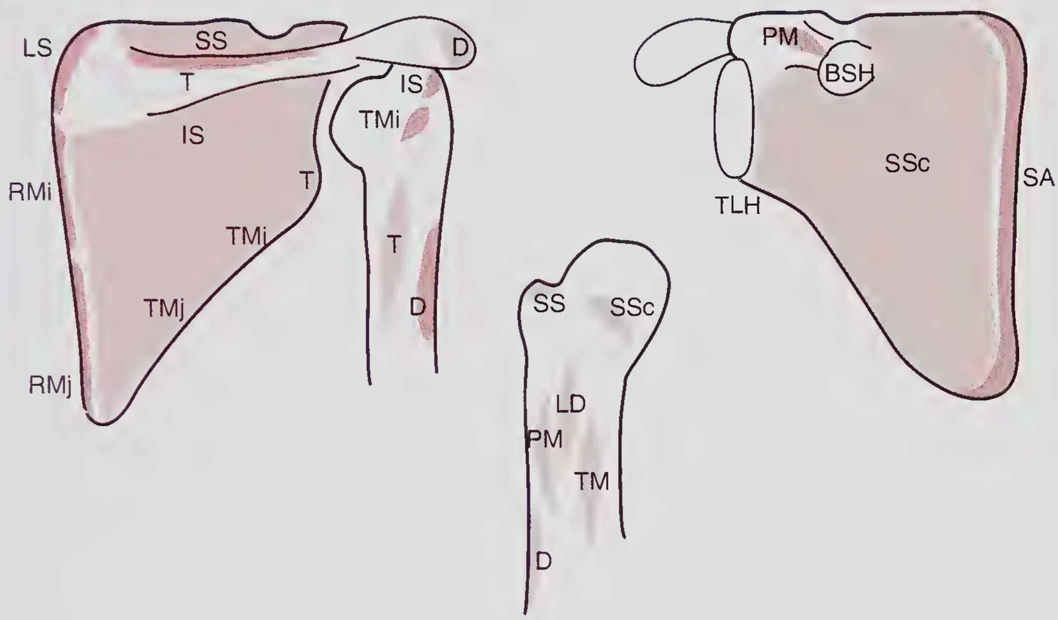


FIGURE 4.10

Muscle on and From Scapula The muscles on and from the scapula are shown. SS indicates supraspinous; LS, levator muscle of scapula; D, deltoid; T, trapezius; RMi, rhomboid minor; RMj, rhomboid major; IS, infraspinous; TMi, teres minor; TMj, teres major; SSc, subscapular; BSH, biceps short head; TLH, triceps long head; PM, pectoralis major (greater pectoral); SA, anterior serratus; LD, latissimus dorsi.

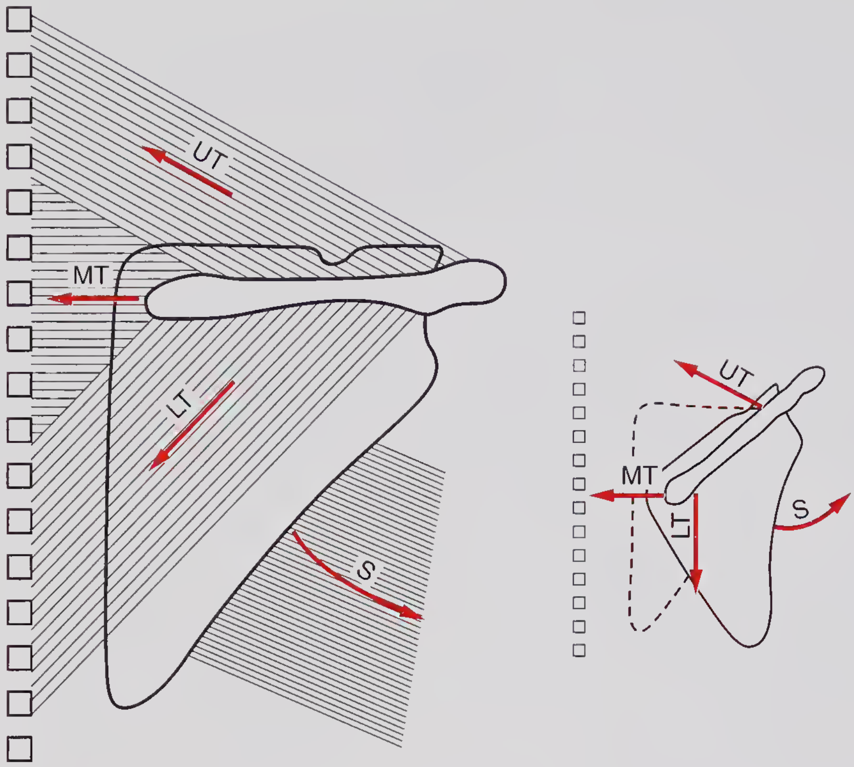


FIGURE 4.11

Scapular Rotators Muscles that support and rotate scapula are upper trapezius (UT), middle trapezius (MT), and lower trapezius (LT), and serratus (S).

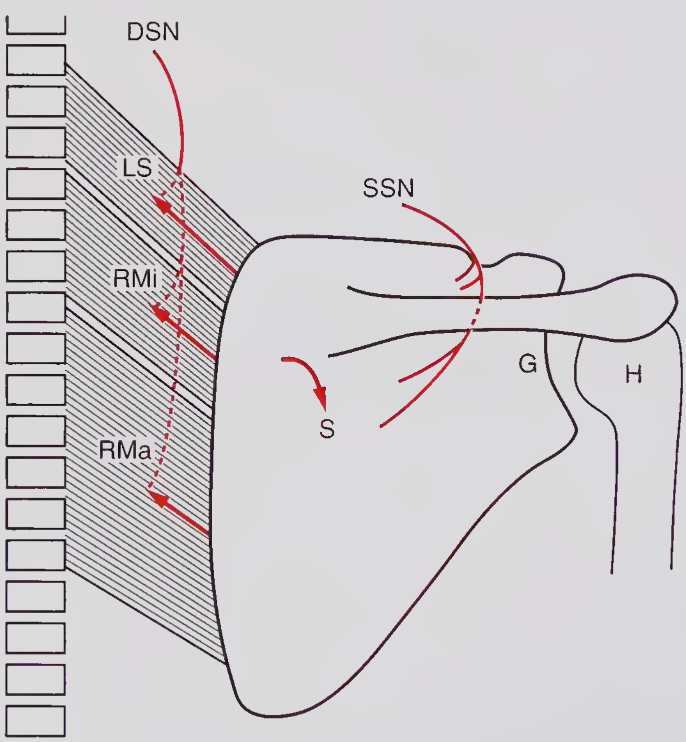


FIGURE 4.12

Downward Scapular Rotators Downward rotators of scapula (S) (curved arrow) are levator scapulae (LS), rhomboid major (RMa), and rhomboid minor (RMi). These muscles are innervated by dorsal scapular nerve (DSN). SSN indicates suprascapular nerve; G, glenoid fossa; and H, humerus.

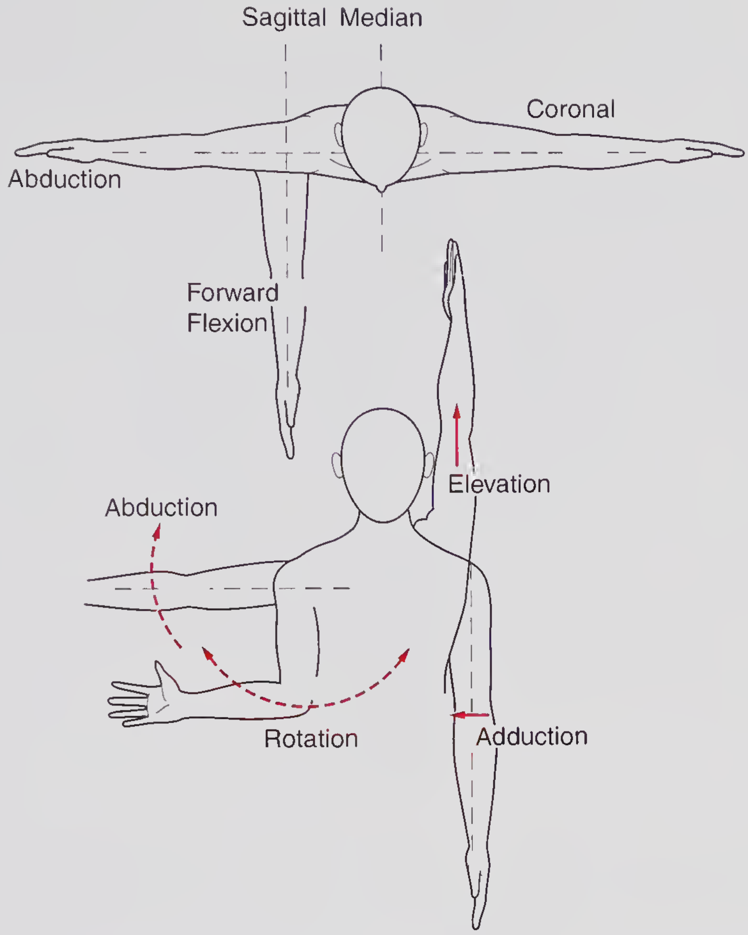


FIGURE 4.13

Planes of Arm Movement Planes of arm movement indicate direction of movement as relates to the body. All planes are related to those viewed from above and from front.

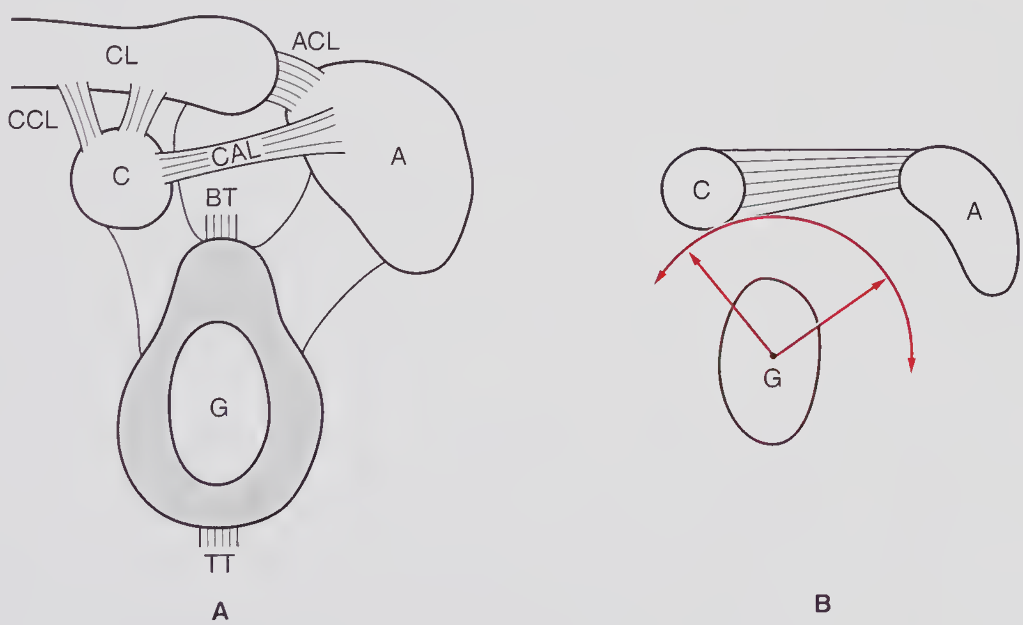


FIGURE 4.14

Site of Glenoid Fossa A, Glenoid fossa (G) is below and lateral to coracoid process (C) and below acromion (A). Biceps tendon (BT) originates from upper margin of fossa. B, Movement (arrows) of humeral head within fossa. ACL indicates acromioclavicular ligament; CCL, coracoclavicular ligaments; CL, clavicle; CAL, coracoacromial ligament; and TT, triceps tendon.

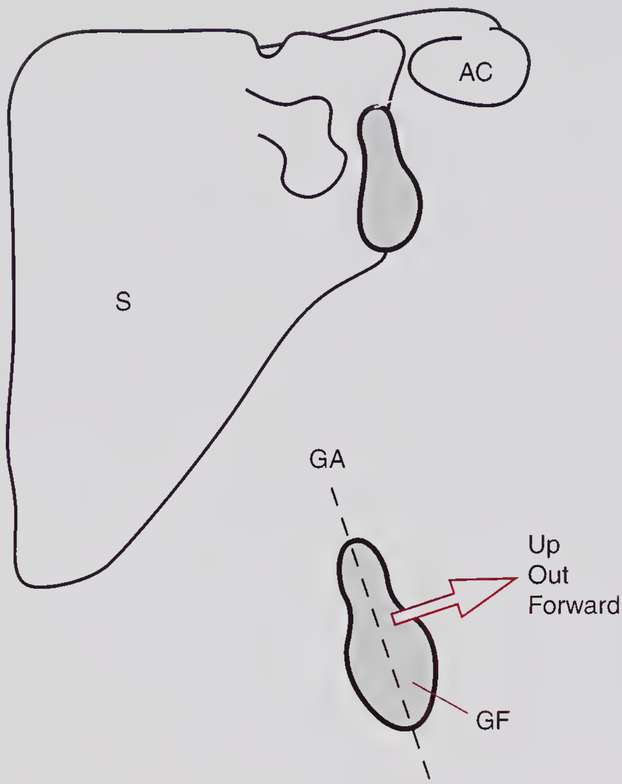


FIGURE 4.15

Facing of Glenoid Fossa Glenoid fossa (GF) and its angulation. AC indicates acromium; S, scapula; and GA, glenoid angle.

THE GLENOHUMERAL JOINT

The glenohumeral joint, the humeral head within the glenoid fossa, is clinically termed the "shoulder joint," as most arm-hand-finger functions require movement or stabilization of the joint. It has been made apparent, however, that the scapulocostal joint is equally important in upper extremity movement.

The glenohumeral joint contains many tissues that are functionally needed and simultaneously are the tissue sites of injury or impairment. The "joint" composes the area of the acromion and coracoacromial ligament overhead and the glenoid fossa of the scapula medially. The long head of the biceps tendon passes over the humeral head in its sulcus. The "rotator cuff," composed of the conjoined tendon of the supraspinous, infraspinous, and teres major muscles, passes over the humerus and attaches to its greater tuberosity. The synovial capsule contains synovial fluid to lubricate all these tissues during movement (Figure 4.16).

The glenoid fossa exemplifies congruency, an engineering term initially defined by MacConnaill[1-3] (Figure 4.17). This concept of joint movement needs to be highlighted in a discussion of functional anatomy, as congruity plays a vital role in how most, if not all, joints of the body function. Rotation occurs about an axis at right angles to the weight-bearing surface

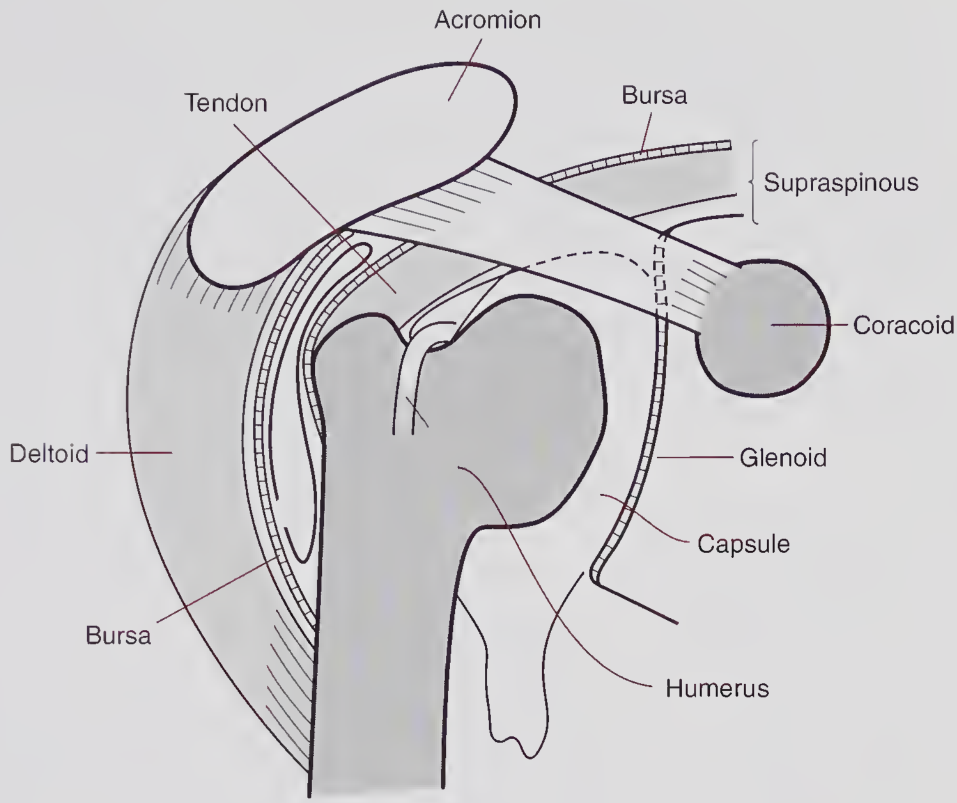


FIGURE 4.16

Contents of Glenohumeral Joint Contents of glenohumeral joint include head of humerus, glenoid fossa, subdeltoid bursa, glenohumeral capsule, tendon of long head of biceps, conjoined tendon of rotator cuff, fascia between undersurface of deltoid muscle, and coracoacromial ligament. Space between coracoacromial ligament and humeral head is termed *suprahumeral joint*.

of a joint but cannot be brought about by single muscles, which, by contracting, cause a mixture of swing and rotation.[4]

In the static shoulder with the arm dependent, the humerus would, by virtue of gravity and the weight of the upper extremity, literally dislocate downward out of the shallow glenoid fossa, which is also at an angle from pure verticality (Figure 4.18).

The glenohumeral capsule is very thin and has limited flexibility (Figure 4.19). It is not strong enough to prevent downward subluxation if not assisted by the rotator cuff. It retracts when the arm is abducted or forward flexed, further allowing instability of the joint during these movements (Figure 4.20).

The integrity of the capsule to stabilize the glenohumeral joint is compounded by the structure of the capsule, which has 3 strands forming "ligaments" and a structural foramen (foramen of Weitbrecht); this foramen allows dislocation of the humeral head (Figure 4.21).

The head of the humerus is thus maintained with stability in the glenoid fossa by the combined action of the rotator cuff and the capsule (Figure 4.22).

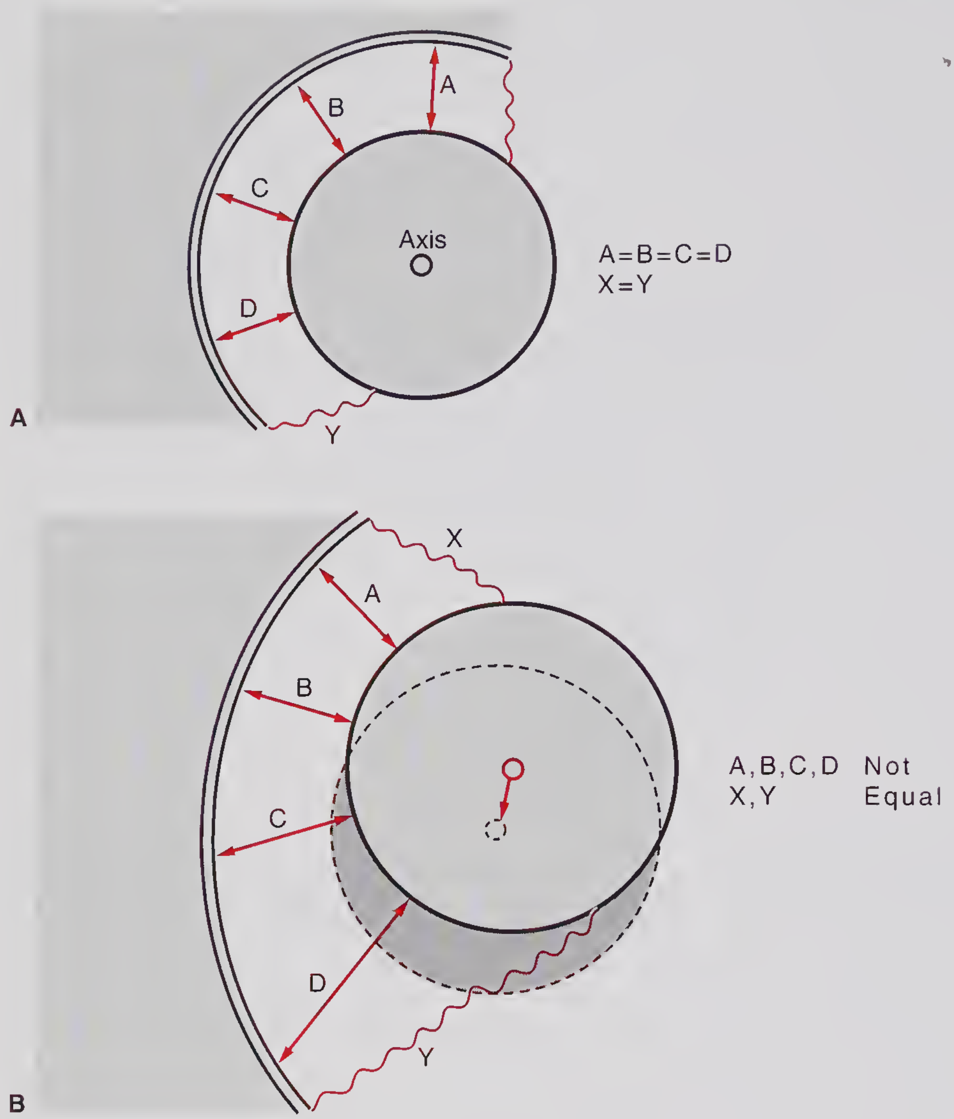


FIGURE 4.17

Congruous and Incongruous Joints A, Congruous joint with symmetrical concave-convex surfaces being equidistant from each other at all points of curvature (A = B = C = D). Rotation of this joint occurs about a fixed central axis of rotation. Muscular (M) action on this joint allows motion but is not needed for stability when the scapula is immobile. Capsule has symmetrical elongation. B, Incongruous joint has asymmetrical articular surface, with concavity and convexity being different; thus, spaces between surfaces are unequal. Convex portion is not "seated" within concave portion and thus may slide down. Movement is gliding, not rotation. Stability requires capsular and muscular intervention. Capsule length varies at all levels of movement.

Rotator Cuff

The so-called rotator cuff is the conjoined tendons of the supraspinous, infraspinous, and teres minor muscles that attach to the greater tuberosity of the humeral head. In the static dependent arm, the supraspinous muscle sustains the head of the humerus in the glenoid fossa by isometric contraction. The tonus of the muscle (ie, the isometric contraction) is determined by the spindle system and the Golgi apparatus as to force, which was discussed in Chapter 1 (Figure 4.23).

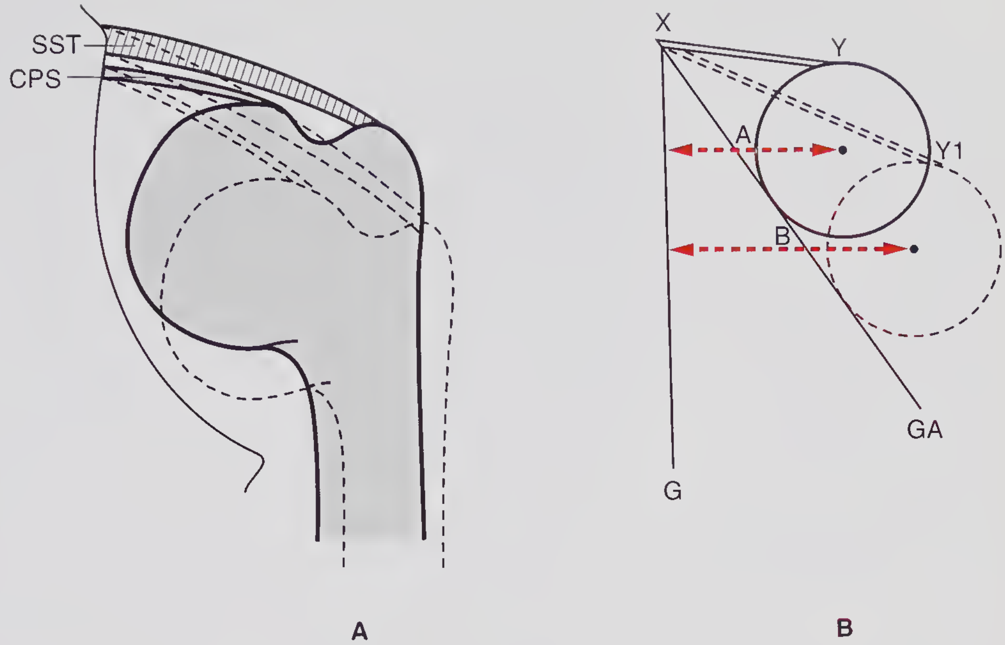


FIGURE 4.18

Downward Glide of Humeral Head on Glenoid Fossa A, Support of humerus by virtue of rotator cuff: supraspinous muscle (SST) and superior aspect of synovial capsule (CPS). B, Vertical gravity force (X-G) compared with inclined line of fossa surface (X-GA). Head of humerus, virtually a ball, tends to roll down inclined plane with its center of axis of rotation (A) moving laterally (B). Capsule and cuff (X-Y) elongate to (X-Y1) and prevent further rolling if intact.

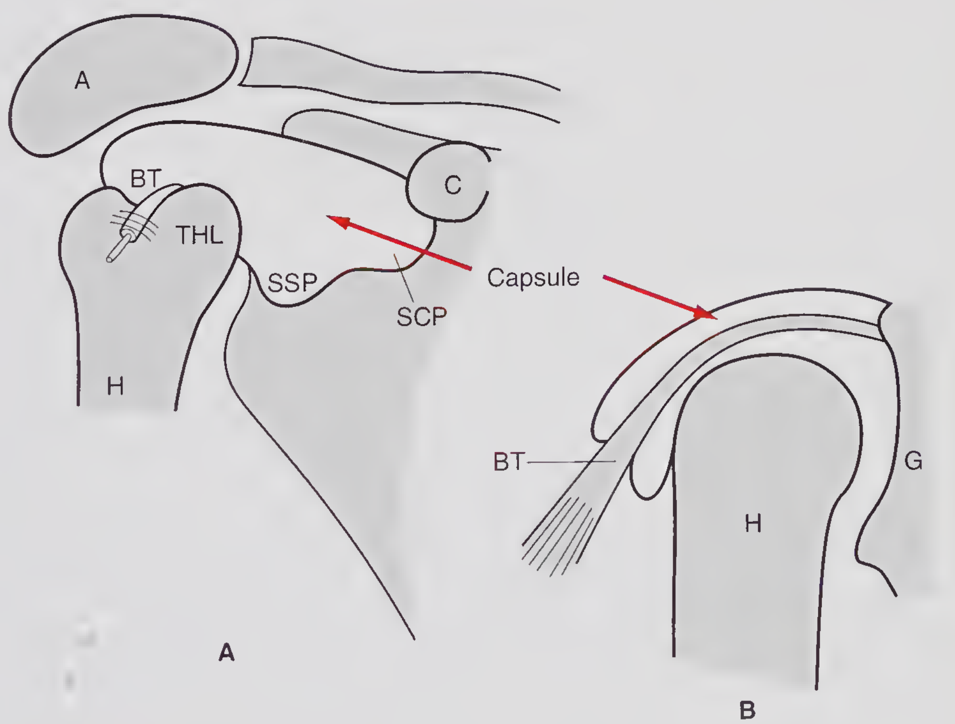


FIGURE 4.19

Glenohumeral Synovial Capsule A, Spacious capsule (C) covers entire humeral head (H). Biceps tendon (BT) invaginates capsule, accompanying it down past transverse humeral ligament (THL), which contains tendon. There are 2 pouches in capsule: subcoracoid (SCP) and subscapular (SSP). B, Invagination of biceps tendon (BT) as well as its attachments to glenoid fossa (G).

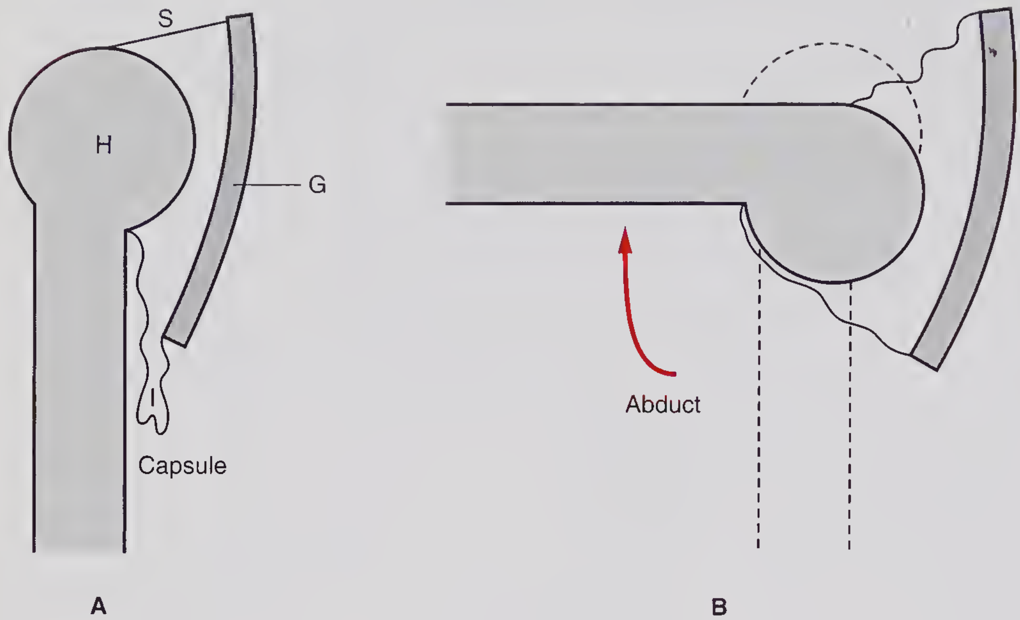


FIGURE 4.20

Flexibility of Glenohumeral Capsule A, Superior capsule (S) being taut during dependency of arm, keeping humeral head (H) seated within glenoid fossa (G). Inferior capsule (I) is redundant. B, During abduction, both capsules become slack.

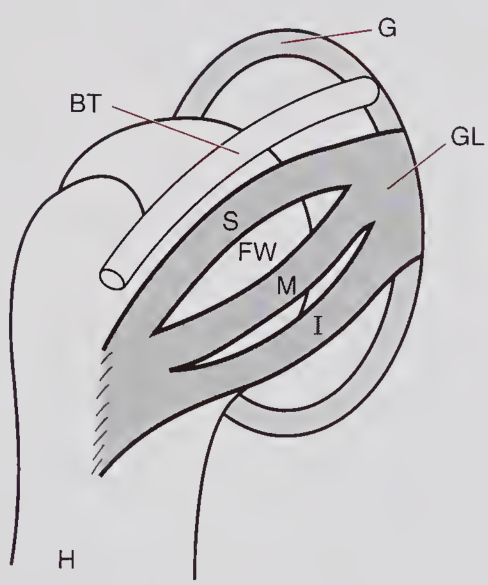


FIGURE 4.21

Anterior Capsule and Glenohumeral Ligaments Three folds of anterior capsule forming glenohumeral ligaments (GL): superior (S), middle (M), and inferior (I). These ligaments attach from anterior ridge of humerus (H) to glenoid fossa (G). Between S and M is foramen of Weitbrecht (FW). BT indicates biceps tendon.

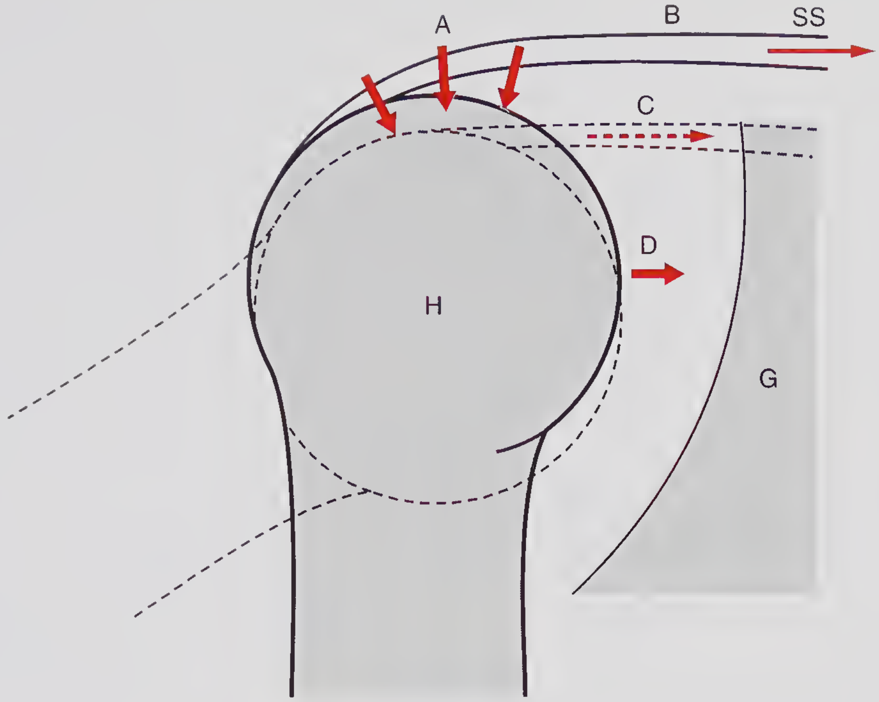


FIGURE 4.22

Support Structures of Glenohumeral Joint Humeral head (H) seated in glenoid fossa (G) prevents downward subluxation against gravity (A, thick, long arrows) by inward pull (thin arrow and dotted arrow) of conjoined tendon (B) of supraspinous muscle (SS) and superior aspect of capsule (C). D indicates active lateral displacement, which is possible.

Kinetic Action of Muscles of the Glenohumeral Joint

As the humerus either abducts or flexes anteriorly or posteriorly, the humeral head must glide-rotate on the glenoid fossa. This is the decalage mentioned by MacConnaill[4]—essentially "coupling" of the humerus on the glenoid fossa.

Glenohumeral movement is a complex action dictated by the anatomical structures of the articulation. As the arm (humerus) begins abduction or flexion, it moves to a degree ultimately limited by the overhanging acromion or the coracoacromial ligament or both. With the arm "neutral" (no rotation) and no scapular motion, 90 degrees of abduction is possible before the greater tuberosity, which lies lateral to the bicipital groove impinges on the overhanging acromion and the coracoacromial ligament. With the arm internally rotated, the greater tuberosity impinges after only 60 degrees of abduction. With external rotation, the greater tuberosity

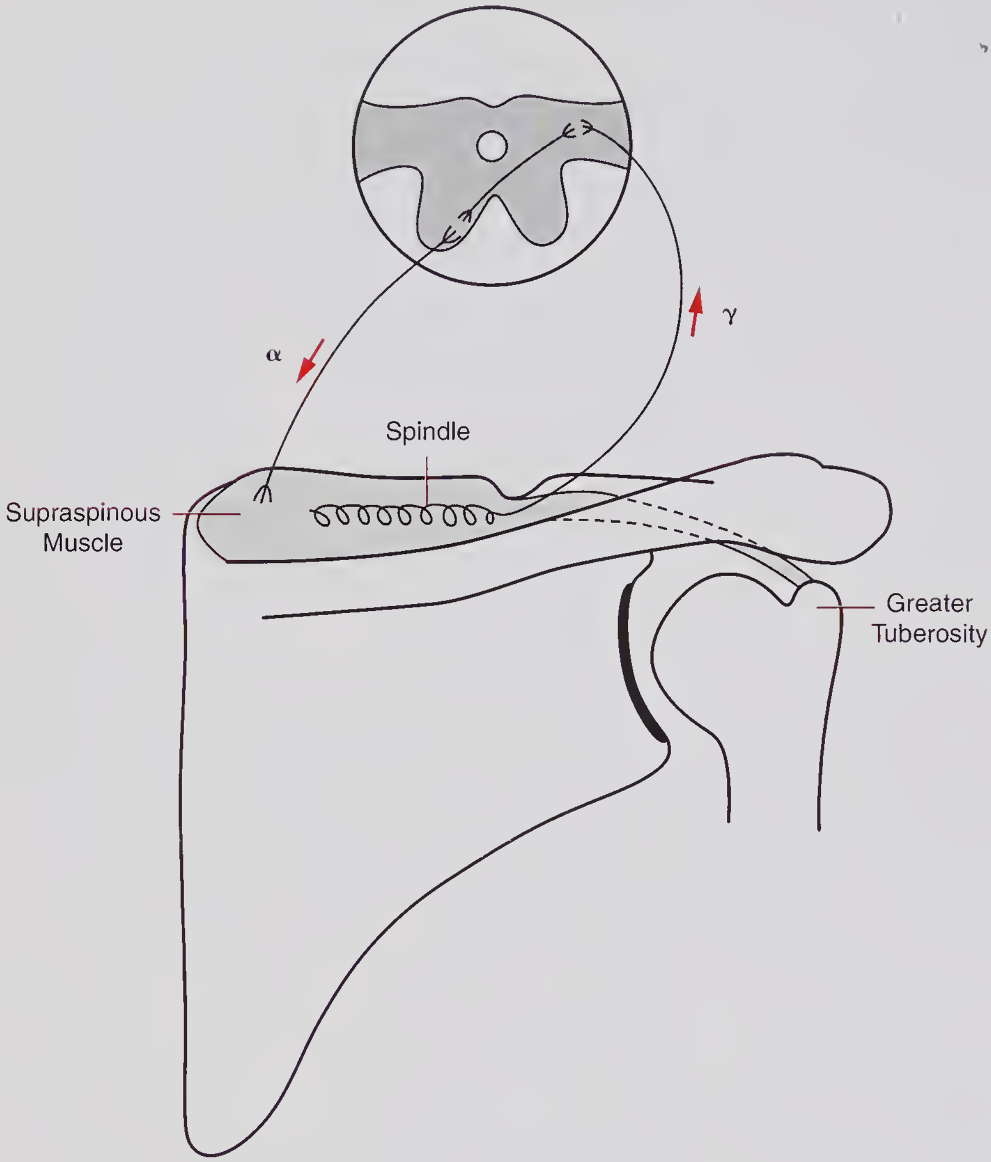


FIGURE 4.23

Supraspinous Muscle Function in Static Arm Posture Supraspinous muscle, which originates in supraspinous sulcus of scapula, has its tendon pass under acromion and attach to greater tuberosity of humeral head. Muscle sustains appropriate amount of tension as mediated by spindle system, which has efferent (motor, alpha) fibers and sensory (gamma) fibers to spinal cord.

passes behind the coracoacromial ligament and the overhanging acromial process and is able to abduct and elevate to approximately 120 degrees. This indicates that abduction and overhead elevation of the arm requires simultaneous external rotation of the humerus (Figure 4.24).

The term *rotator cuff* indicates that, in addition to static support of the dependent arm, the cuff abducts and forward flexes the arm with simultaneous rotation as needed to pass by the acromion and coracoacromial ligament (Figures 4.25, 4.26, 4.27).

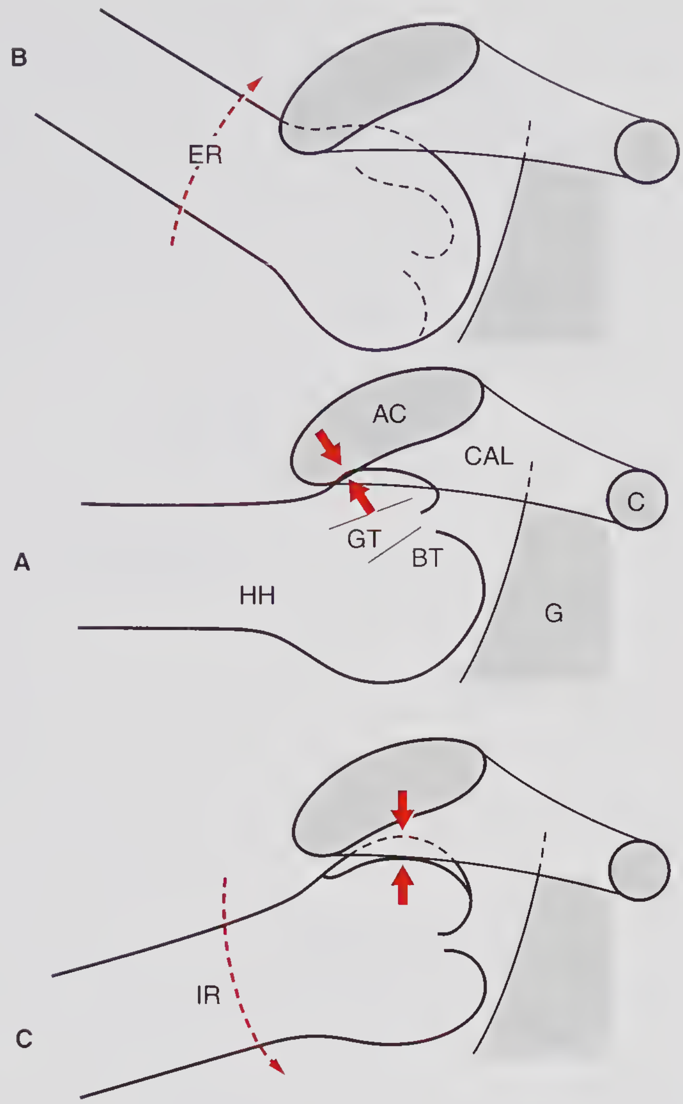


FIGURE 4.24

Overhead Movement of Arm at Glenohumeral Joint A, In neutral rotation, abduction of arm is possible to 90 degrees before greater tuberosity (GT) of humeral head (HH) impinges on acromial process (AC) and/or coracoacromial ligament (CAL). B, With simultaneous external rotation (ER) of humerus, arm can raise to 120 degrees as greater tuberosity passes behind coracoacromial ligament. C, With internally rotated humerus (IR), impingement occurs early, permitting only 60 degrees of abduction. G indicates glenoid fossa; BT, bicipital tendon.

The conjoined tendon that attaches from the muscles to the greater tuberosity is poorly supplied by the vascular system, causing a "critical zone" that limits the stresses the tendon can endure. Most tendons are substantially avascular with limited arterial supply (Figure 4.28).

There are muscles that rotate the humerus other than muscles originating from the scapula, namely, the latissimus dorsi and the greater and smaller pectoral muscles (Figures 4.29, 4.30).

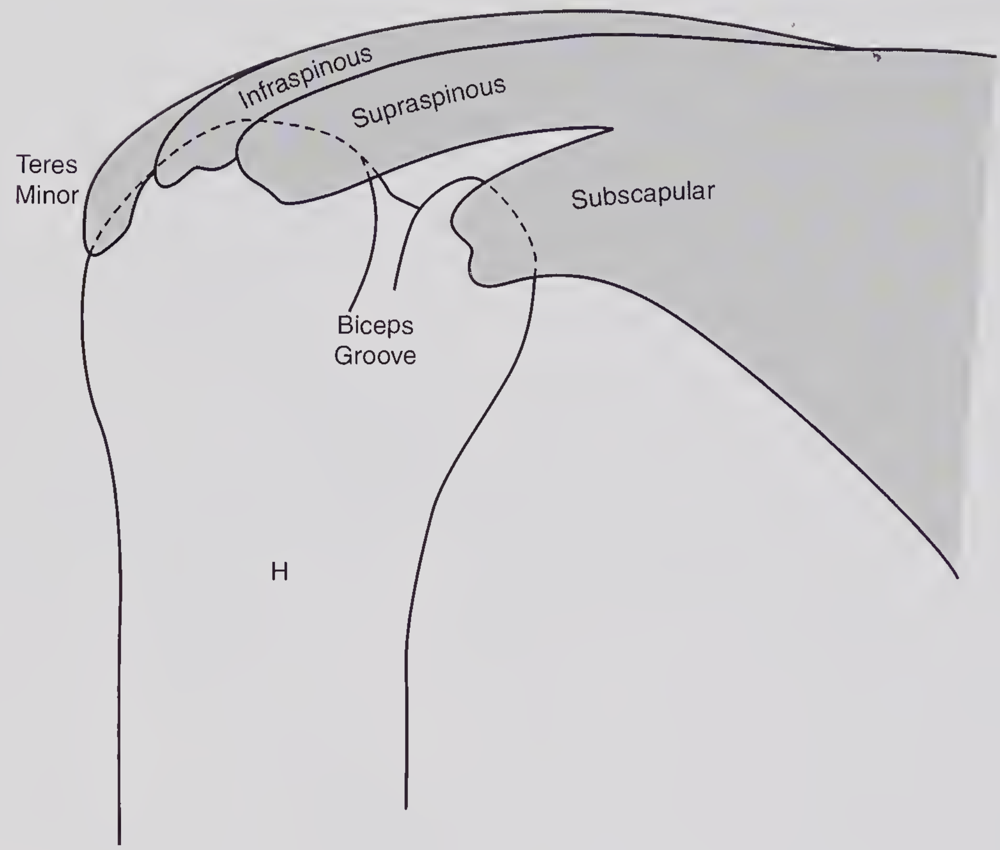


FIGURE 4.25

Rotator Cuff Rotator cuff is a conjoined tendon of several muscles—supraspinous, infraspinous, subscapular, and teres minor muscles. All these muscles except subscapular attach to greater tuberosity of head of humerus (H), lateral to bicipital groove, and subscapular muscle tendon attaches to lesser tuberosity.

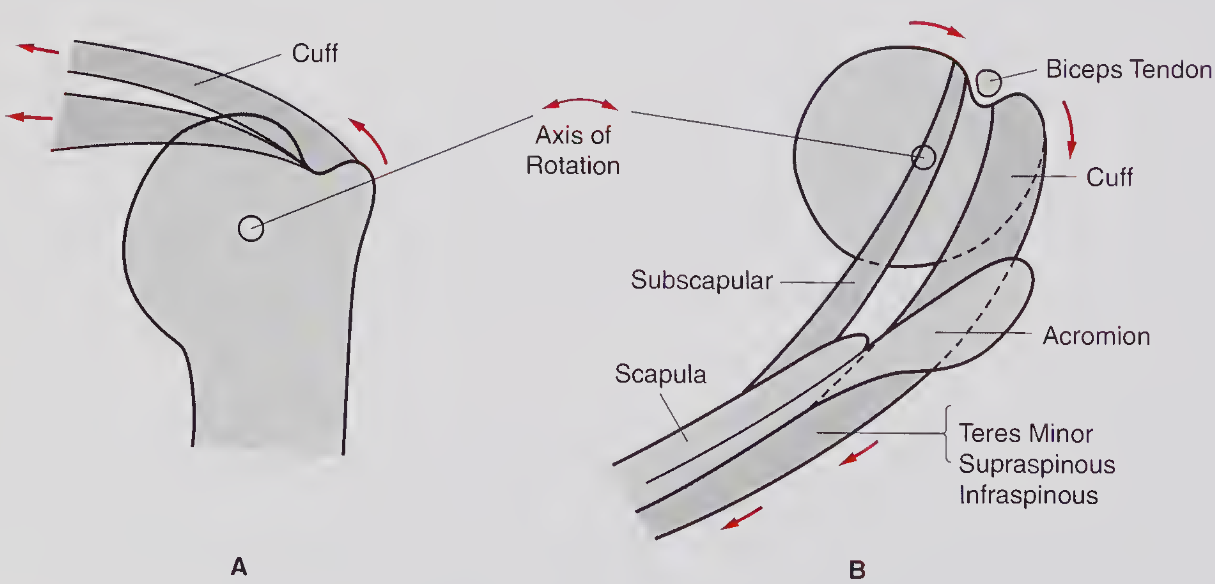


FIGURE 4.26

Rotational Axis of Rotation of Cuff Action A, Abduction about axis of rotation by cuff contraction. B, External rotation of humerus from cuff contraction about that axis. Cuff originates on external surface of scapula and is eccentric to humeral axis. Subscapular muscle originates on internal surface of scapula and internally rotates humerus.

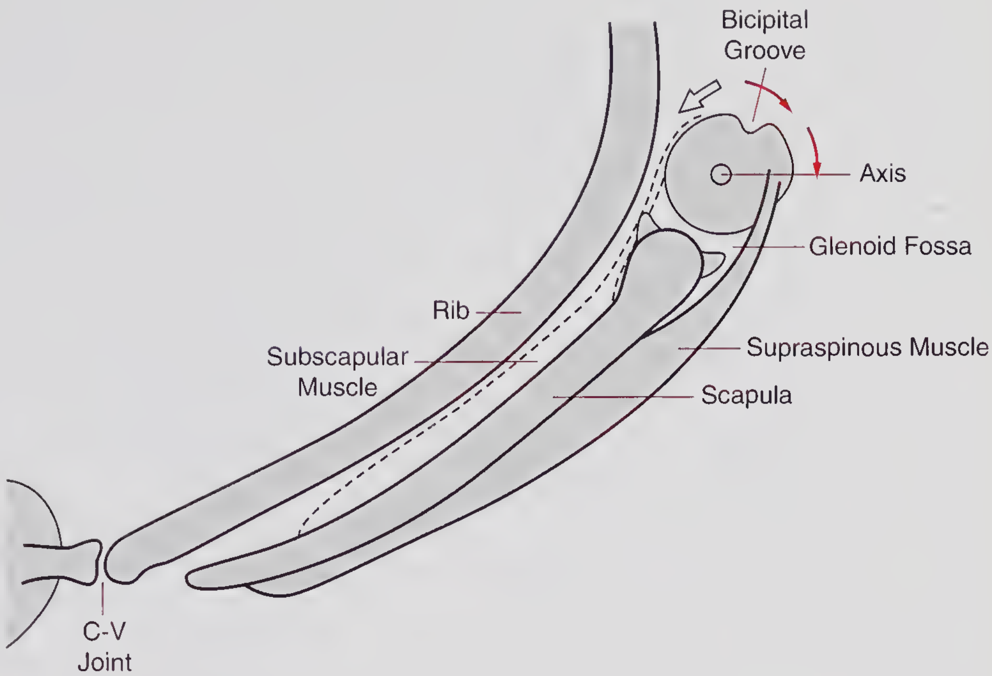


FIGURE 4.27

Rotators of Humerus Viewed from above, scapula lies on rib cage. Supraspinous muscle originates from external surface, is attached to greater tuberosity eccentric to axis of rotation, and externally rotates arm. Subscapular muscle (dotted line) internally rotates arm. C-V indicates costovertebral.

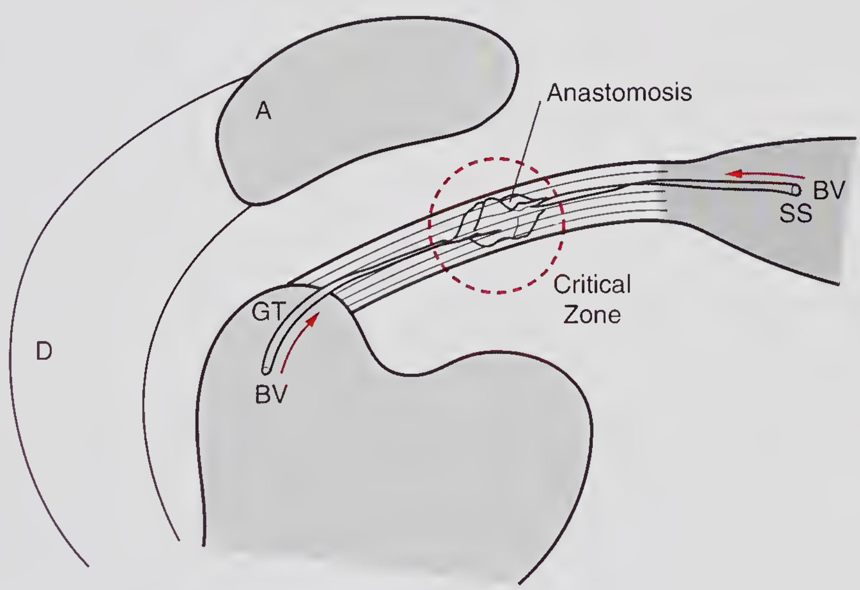


FIGURE 4.28

Critical Zone of Conjoined Tendon Conjoined tendon receives its blood supply from bony arteries of humerus (BV) at greater tuberosity (GT) and descending arteries from supraspinous muscle (SS). Central anastomosis forms critical zone that is susceptible to traction and compressive forces. A indicates acromion; D, deltoid muscle.

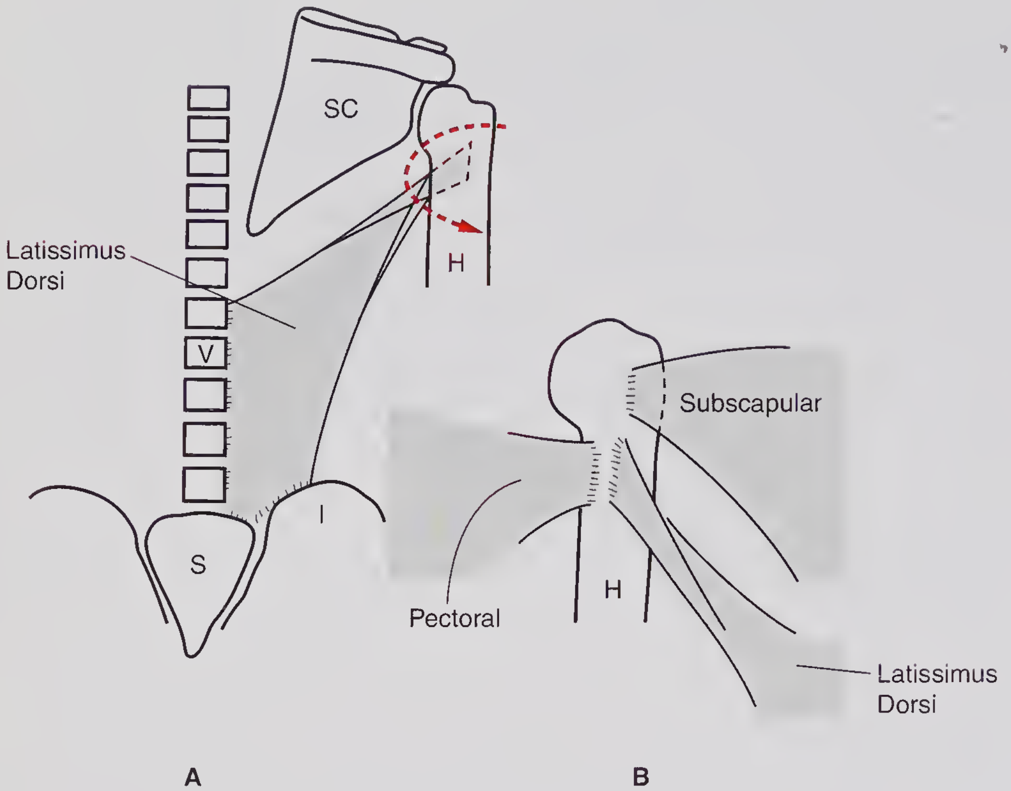


FIGURE 4.29

Rotators of Arm A, Viewed from rear, latissimus dorsi muscle originates from lower thoracic vertebrae and all lumbar vertebrae (V) and os ilium (I) to attach to inner aspect of humerus (H), thus becoming an internal rotator (curved arrow). S indicates sacrum; SC, scapula. B, Viewed from front, greater and smaller pectoral muscles attach from rib cage to insert on anterior aspect of humerus and thus contract to internally rotate humerus. Attachment sites of latissimus dorsi and subscapular muscles are shown.

The head of the humerus is supported by the musculature in every aspect except the inferior aspect (Figures 4.31, 4.32).

Kinetic Motion of the Glenohumeral Joint

The movement of the glenohumeral joint is a complex action that emphasizes the incongruity of that joint. As the arm abducts, or forward-posteriorly flexes, the head of the humerus glides down and forward and backward on the glenoid fossa. This is a muscular action of the rotator cuff and other glenohumeral muscles, such as the deltoid, latissimus dorsi, and the greater and smaller pectoral muscles acting in coordination. From total dependency (0 degrees) to overhead elevation (180 degrees), the humerus must abduct (forward flexion); then it gradually and simultaneously externally rotates to avoid the rotator cuff tendon being impinged on the overhanging acromion and coracohumeral ligament, known as the "painful arc" between 60 and 120 degrees (Figure 4.33).

The muscle action that abducts and totally elevates the arm involves the muscles of the rotator cuff and the deltoid muscle. The deltoid muscle, by far the more powerful, is not an abductor initially on abduction and forward

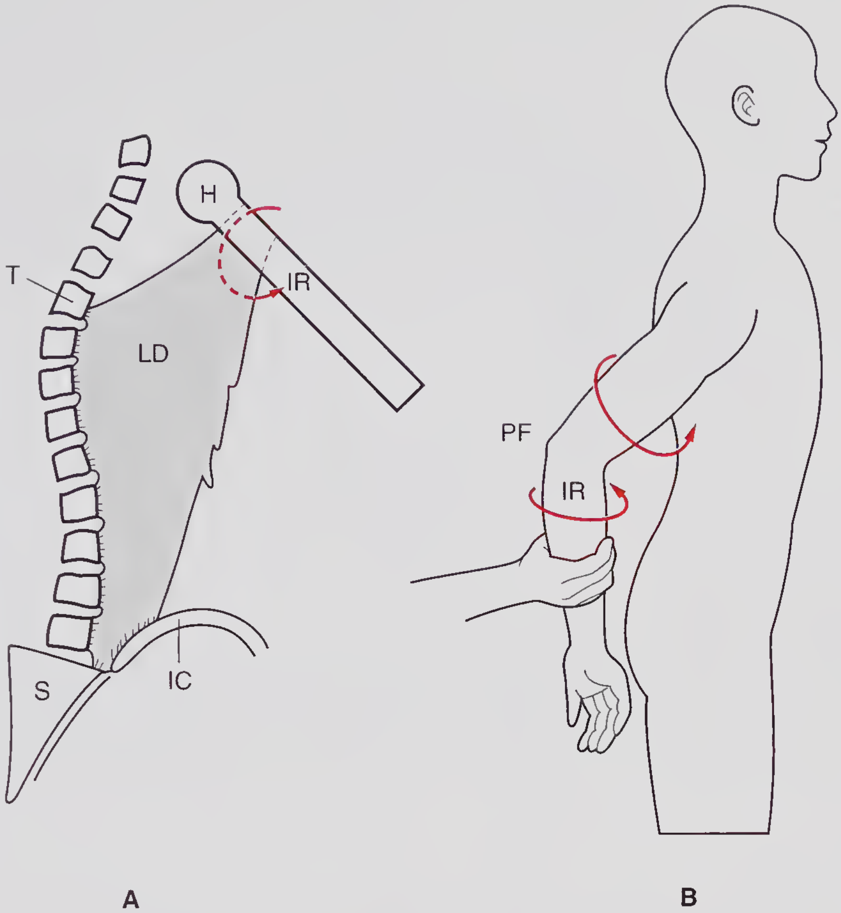


FIGURE 4.30

Functional Testing of Latissimus Dorsi Muscle A, Origin and insertion of latissimus dorsi muscle (LD), inserting on humerus (H) and causing internal rotation (curved arrow, IR). S indicates sacrum; IC, iliac crest; T, thoracic vertebrae. B, Examiner resisting posterior flexion (PF) and internal rotation (IR), which are motions of latissimus dorsi muscle.

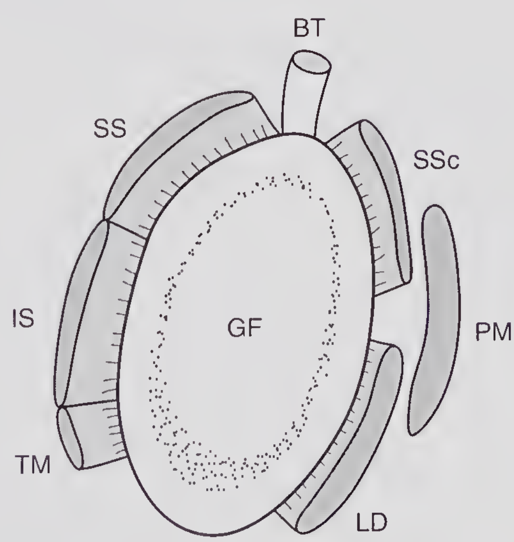


FIGURE 4.31

Muscles Stabilizing Humeral Head During Action Glenoid fossa (GF) that seats head of humerus is encircled by numerous muscles: supraspinous (SS), infraspinous (IS), teres minor (TM), subscapular (SSc), latissimus dorsi (LD), and greater pectoral (pectoralis major, PM). Biceps tendon (BT) also stabilizes head of humerus.

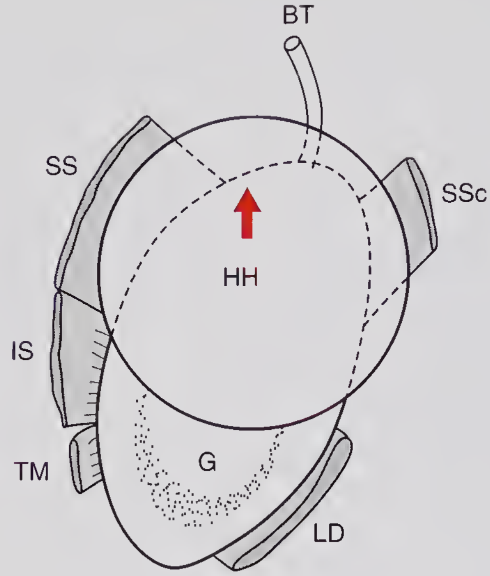


FIGURE 4.32

Head of Humerus in Confines of Cuff Musculature Head of humerus (HH) is supported superiorly (arrow), but there is deficiency inferiorly between teres minor (TM) and latissimus dorsi (LD) muscles. G indicates glenoid fossa; BT, biceps tendon; SS, supraspinous muscle; IS, infraspinous muscle; SSc, subscapular muscle.

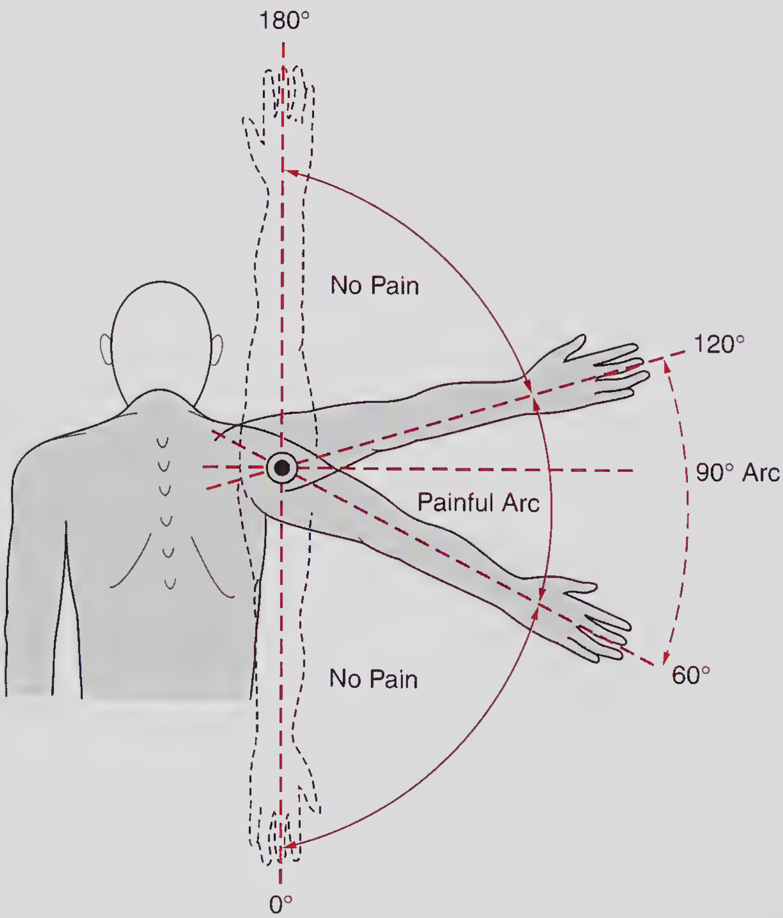


FIGURE 4.33

Painful Arc of Arm: Abduction-Elevation Viewed from behind, arm goes from total dependency (0 degrees) to total overhead elevation (180 degrees). Between 60 and 120 degrees, arm must abduct-forward flex and externally rotate to avoid impingement on acromion and coracoacromial ligament.

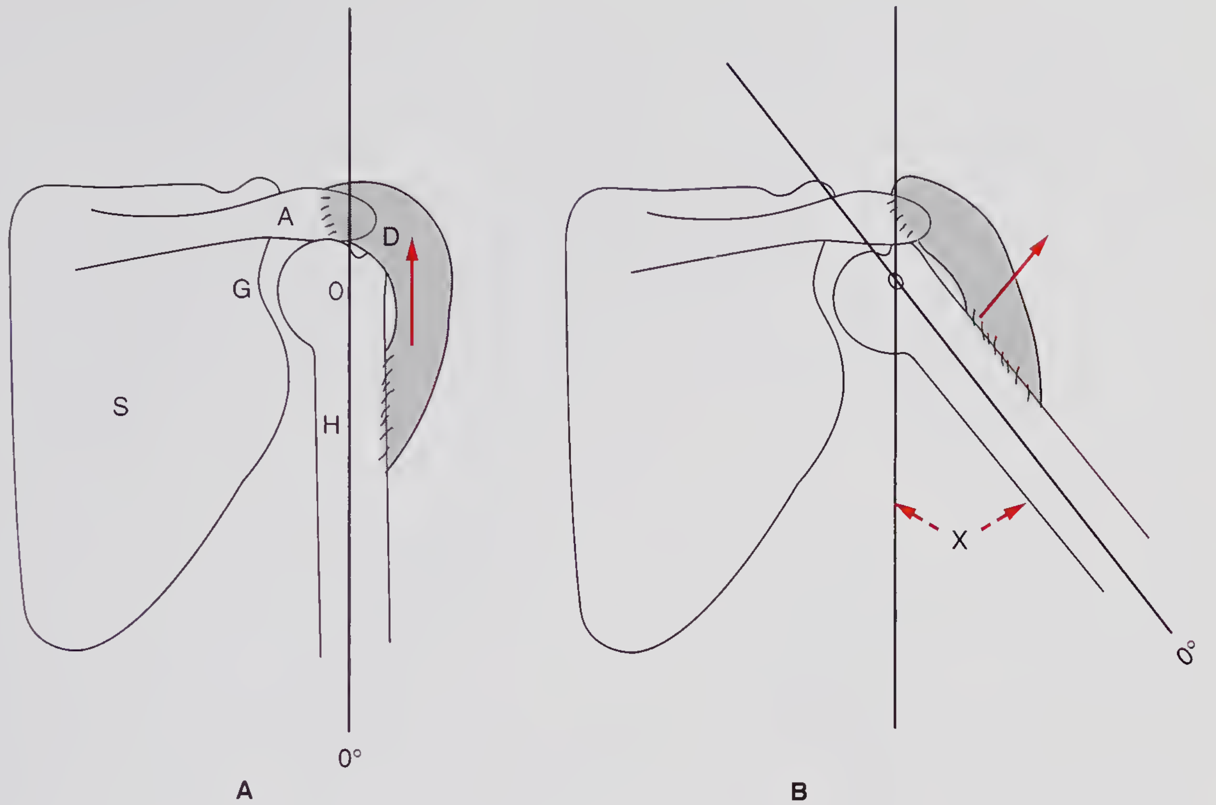


FIGURE 4.34

Action of Deltoid Muscle on Humerus A, With humerus (H) dependent, deltoid muscle (D) originates from acromion (A) and inserts on midshaft of humerus. Its contraction is thus elevation of humerus (dotted arrow in figure B). B, Once abducted (by cuff muscles), deltoid muscle acts at an angle (X) and becomes an abductor and forward flexor.

flexion; in that position, the origin and insertion of the muscles on the humerus are to elevate the arm and avoid impinging the head of the humerus on the overhanging acromion (Figure 4.34).

The rotator cuff muscles abduct and flex the arm while simultaneously depressing the head of the humerus on the glenoid fossa (Figure 4.35).

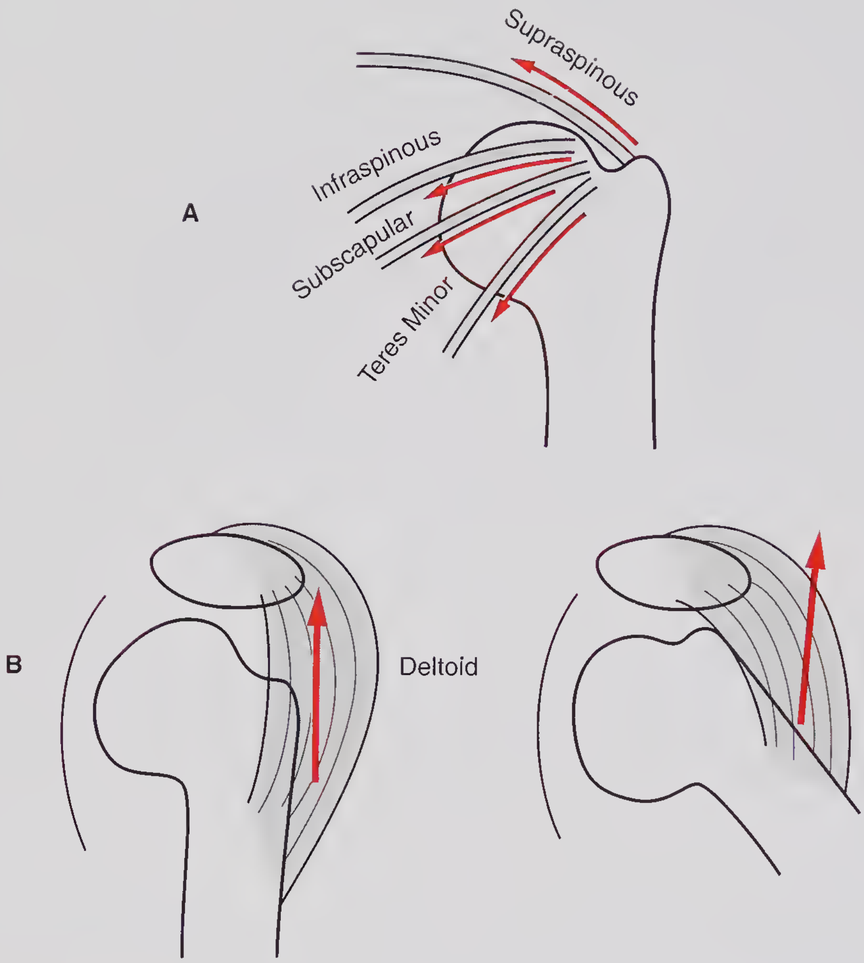


FIGURE 4.35

Muscles Acting on Humeral Head A, Lines of pull of rotator cuff muscles. Supraspinous and infraspinous muscles abduct and rotate head of humerus. Subscapular muscle abducts to lesser degree but also rotates and depresses head of humerus. B, Assistance of deltoid muscle on humerus.

SCAPULOHUMERAL RHYTHM

It has become apparent that without further scapular motion the humerus can abduct and overhead elevate to only 120 degrees when the acromion prevents further motion. The scapula must therefore rotate to remove the acromion from obstruction. This occurs with the scapula rotating about its scapulocostal joint by the muscles that attach to the scapula.

A "rhythm" has been postulated, depicting the degrees of scapular rotation as contrasted to the degrees of glenohumeral rotation. A ratio of 2:1—2 degrees of glenohumeral rotation to every degree of scapular rotation—has been simplistically formulated. This is the *scapulohumeral rhythm* (Figure 4.36).

As the scapula must rotate 60 degrees, the clavicle, which attaches to the acromion, must also rotate 45 degrees (Figure 4.37).

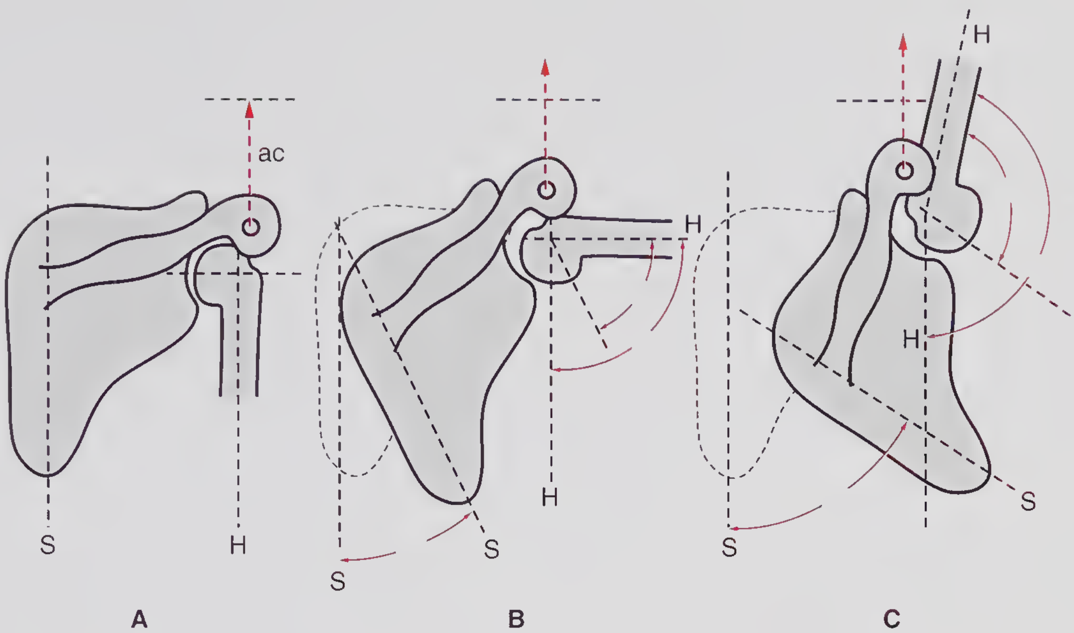


FIGURE 4.36

Scapulohumeral Rhythm A, Dependent arm with vertical alignment of scapula (S) and humerus (H) about axis of acromioclavicular joint (ac). B, As abduction occurs, scapula rotates 30 degrees and humerus rotates 60 degrees, for a total of 90 degrees of arm abduction. C, For further arm overhead elevation (180 degrees), scapula rotates 60 degrees, and humerus rotates on glenoid fossa 120 degrees. Ratio is thus 2:1.

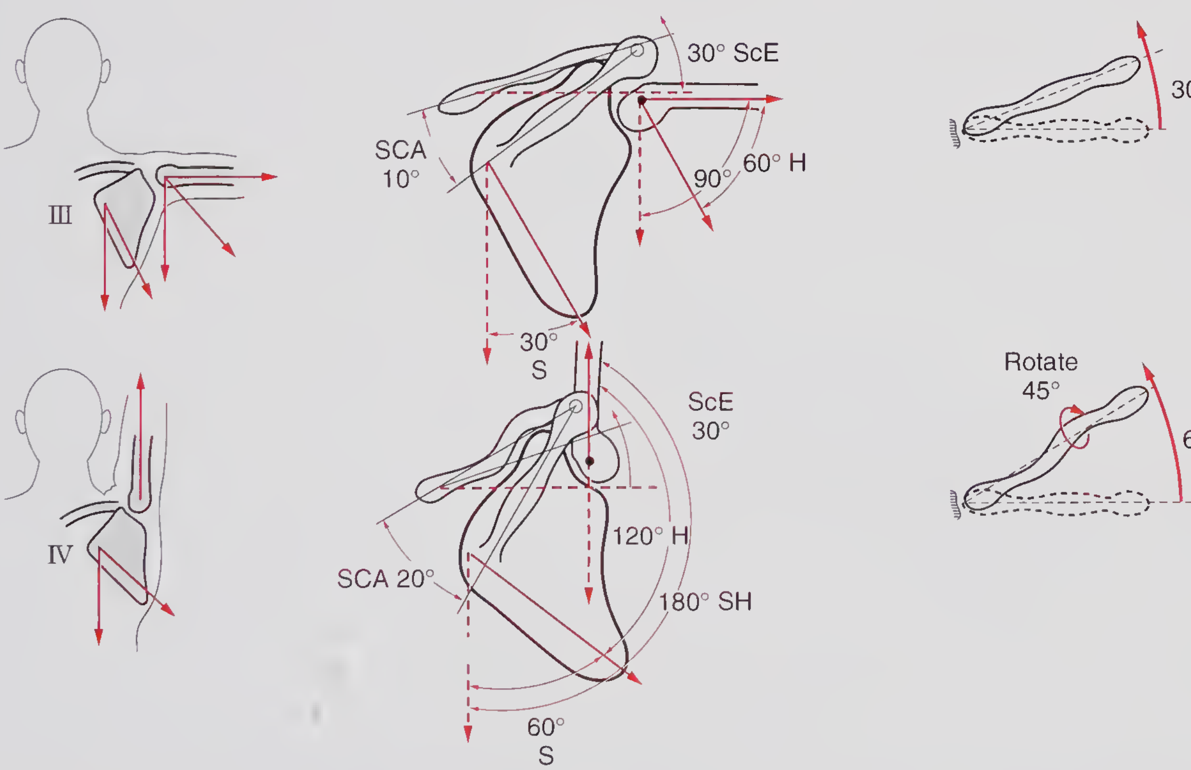


FIGURE 4.37

Clavicular Component of Scapulohumeral Rhythm Third (III, top) phase of scapulohumeral rhythm. Clavicle has elevated 30 degrees without rotation (top right). Fourth (IV, bottom) phase of rhythm, in which clavicle has rotated 45 degrees and scapulohumeral (SH) has elevated to 180 degrees. SCA indicates scapuloclavicular angle; 30 degrees, rotation of scapula (S); ScE, scapular elevation; and H, humerus.

BICIPITAL MECHANISM OF GLENOHUMERAL ACTION

The origin of the long head of the biceps tendon is on the supraglenoid tubercle of the scapula. The tendon leaves the joint through an exit between the superior part of the capsule and the humeral head and enters the intertubercular groove on its way to insert on the radius. As the tendon of the long head passes into the intertubercular groove, it crosses over the humeral head at a right angle (Figure 4.38).

As the arm abducts or forward flexes, the tendon acts as a pulley, causing the humerus to be forced downward. This force is a vector with the biceps contraction and the weight of the arm.

As the arm abducts and externally rotates, the biceps tendon lines up directly over the superior aspect of the humeral head and acts as pulley. The biceps tendon exerts a downward force, preventing the humerus from ascending in the glenohumeral joint. The force of the biceps and the weight of the arm construct a force vector (resultant)[5] (Figure 4.39).

A summary of the scapulohumeral rhythm is now appropriate to include all 4 articulations of the shoulder complex involved.[6,7] The intricate interplay of all these joints results in a coordinated shoulder girdle motion placing the hand in its functional area.

During the first 30 degrees of abduction, the scapula stabilizes the upper extremity. However, once this phase has been reached, the scapula and the humerus move at a 2:1 ratio of movement; thus, for every 2 degrees of

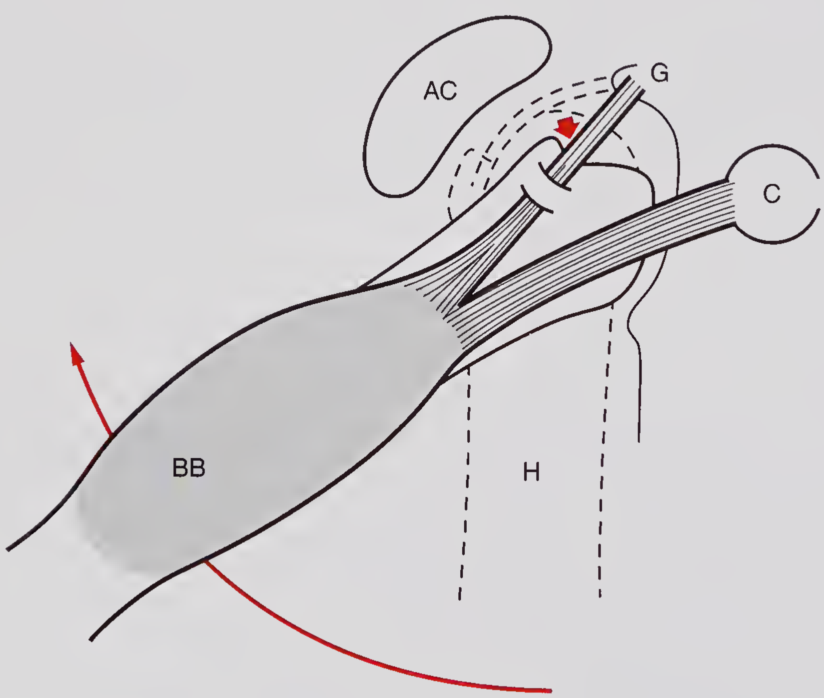


FIGURE 4.38

Biceps Mechanism Long head of biceps (BB), which attaches to supraglenoid tubercle of scapula (G), presses down on humeral head (H) as it abducts. Short head of biceps originates from coracoid process (C). AC indicates acromion.

humeral motion, there is 1 degree of scapular motion. Ultimately, the total arm may reach full (180-degree) overhead elevation.

The 60 degrees of scapular rotation on the chest wall is allowed by the combined motions of the sternoclavicular and the acromioclavicular joints, with commensurate rotation at each. The muscles that activate the scapulohumeral rhythm are all the scapular muscles and the combined glenohumeral muscles: the rotators and the deltoid.

The precise rhythm ratio of 2:1 has been challenged. For instance, one author reported that 175 degrees of arm elevation uses only 50 degrees of scapular rotation,[8] and another report[9] stated that for every 2 degrees of scapular motion there were 3 degrees of humeral motion. These modifications do not greatly alter the accepted 2:1 ratio initially postulated.

Posture has been alluded to throughout this text, and it does play a major role in movement of the shoulder girdle. If there is excessive dorsal kyphosis ("rounded shoulder posture"), the scapula rotates excessively downward and thus places the acromion at a lower level, enhancing earlier entrapment of the abducting-forward flexing humerus as it attempts total elevation (Figure 4.40).

In a limited elevation of the scapulohumeral arm due to whatever cause, only one arm is denied full overhead elevation and thus may mimic postural deficiency, but, by affecting only one arm, posture is not affected (Figure 4.41).

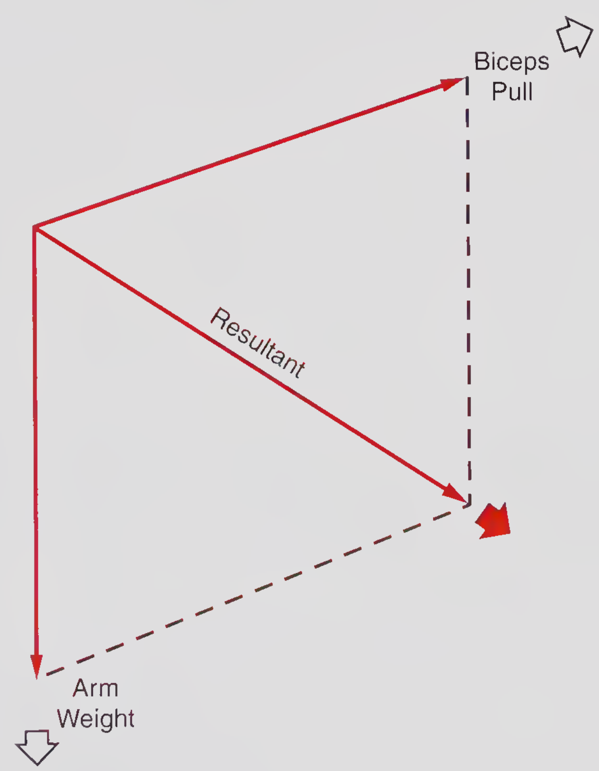


FIGURE 4.39

Vector Forces of Biceps Tendon Vector force is formed by force of biceps muscle through its tendon on head of humerus and weight of arm. Resultant vector force keeps humeral head down.

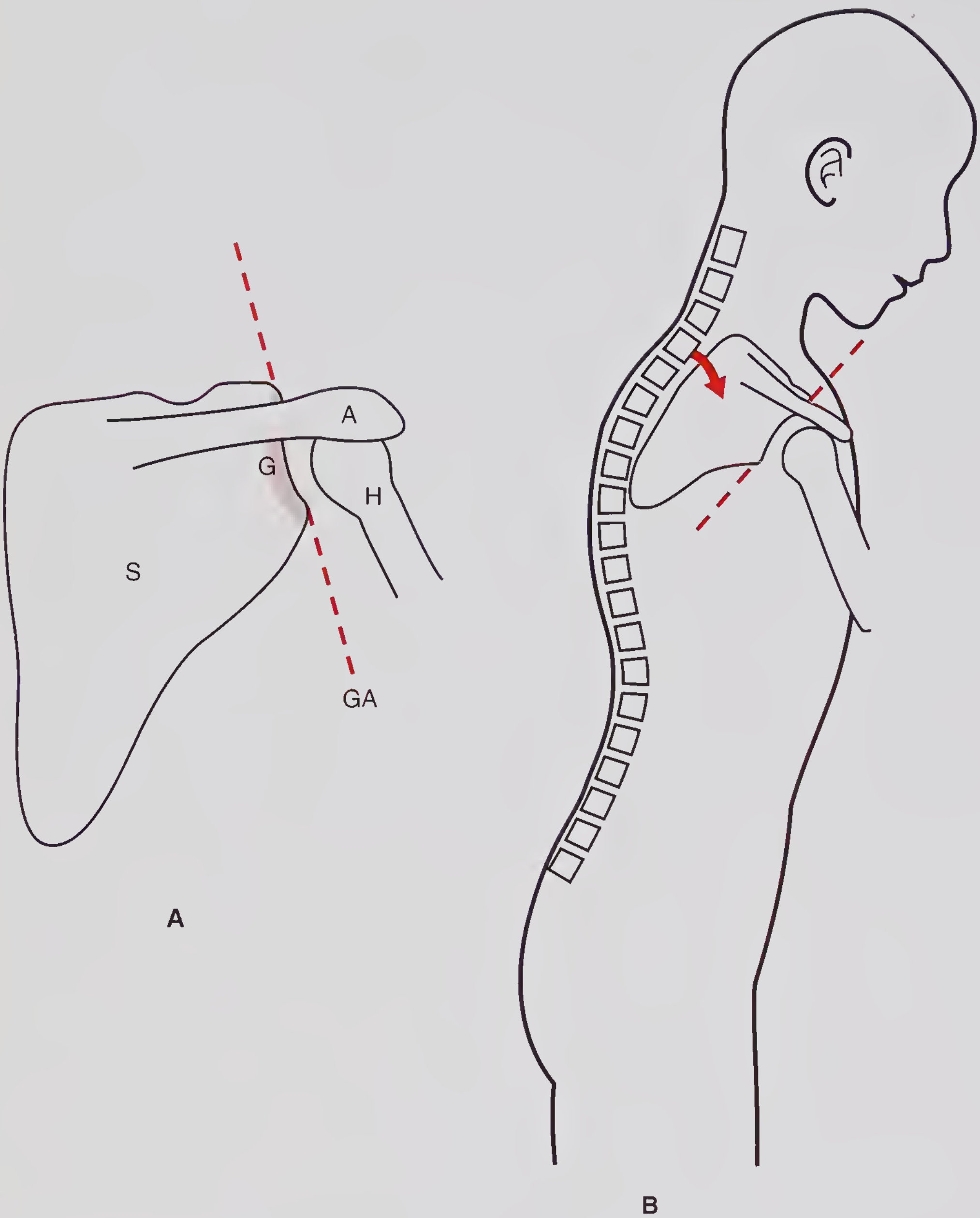


FIGURE 4.40

Effect of Posture on Shoulder Action A, Glenoid angle (GA) with scapula (S) in a physiological position. A indicates acromium; H, humerus. B, The dorsal kyphotic posture rotates (curved arrow) the scapula downward and changes the glenoid angle and the position of the acromium.

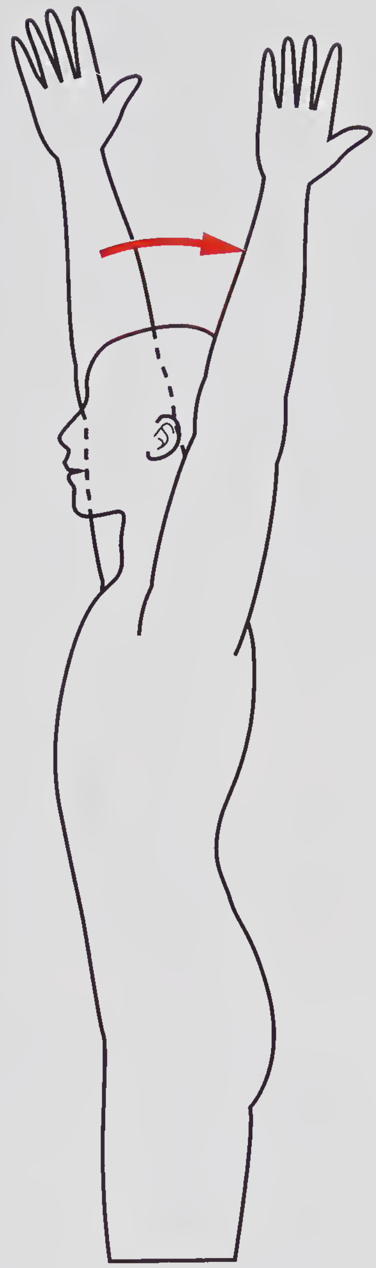


FIGURE 4.41

Unilateral Impaired Overhead Elevation of Arm Overhead elevation of only left arm (right in figure) is restricted, indicating unilateral glenohumeral restriction, not postural component.

THORACIC OUTLET

As there are controversial diagnoses of a thoracic outlet syndrome, the functional anatomical structures of the outlet need clarification. The thoracic outlet consists of the space between the first rib and the scalene muscles, through which the brachial plexus and the subclavian artery and vein pass as they descend as a neurovascular bundle between the first rib and the clavicle (Figures 4.42, 4.43).

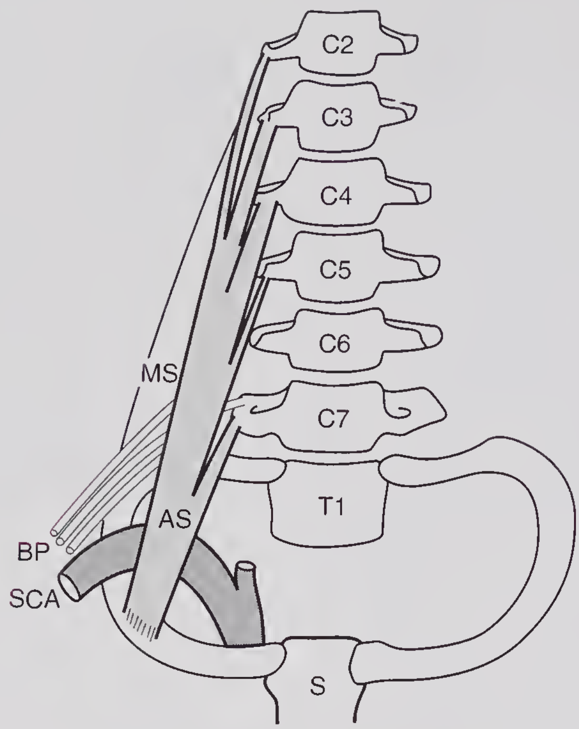


FIGURE 4.42

Thoracic Outlet Anterior scalene muscle (AS), which originates from lateral process of cervical vertebrae (C2 through C7), descends to attach to first rib. Middle scalene muscle (MS) has similar origin but attaches more laterally to first rib, forming opening through which brachial plexus (BP) and subclavian artery (SCA) pass.

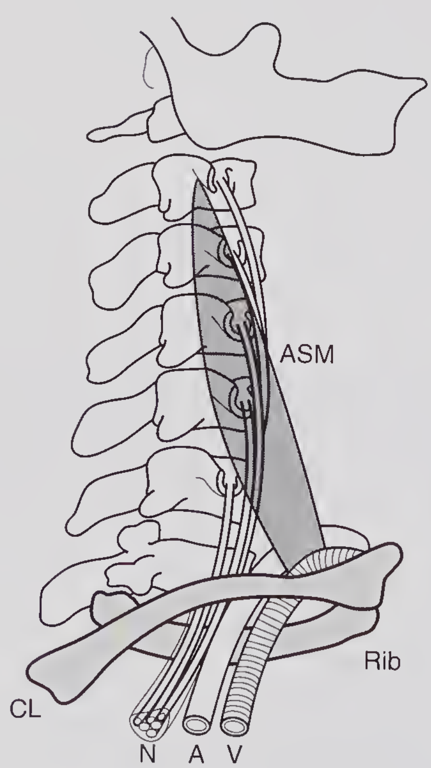


FIGURE 4.43

Neurovascular Bundle Passing Through Outlet Neurovascular bundle passing through thoracic outlet contains nerves (N), artery (A), and vein (V), which are divided by anterior scalene muscle (ASM). Neurovascular bundle between first rib and ultimately behind clavicle (CL).

FUNCTIONAL ANATOMY OF PAINFUL SYNDROMES

Painful syndromes of the shoulder rotator cuff become evidenced by a "painful arc." (Refer to Figure 4.33.) There is pain when the inflamed rotator tendon passes under the overhanging acromion and coracoacromial ligament, causing pain and ultimately limitation of movement. By limited range of motion at the glenohumeral joint, the scapular "rhythm" is impaired and the scapular phase becomes the mover of the shoulder girdle, with no glenohumeral motion causing the "shrugging motion" on abduction (Figure 4.44).

Another classic term used in shoulder pathology is the use of the Codman exercise, which merits discussion in functional anatomy. The purpose of this exercise is to maintain and improve the glenohumeral range without using active muscular contraction (Figure 4.45).

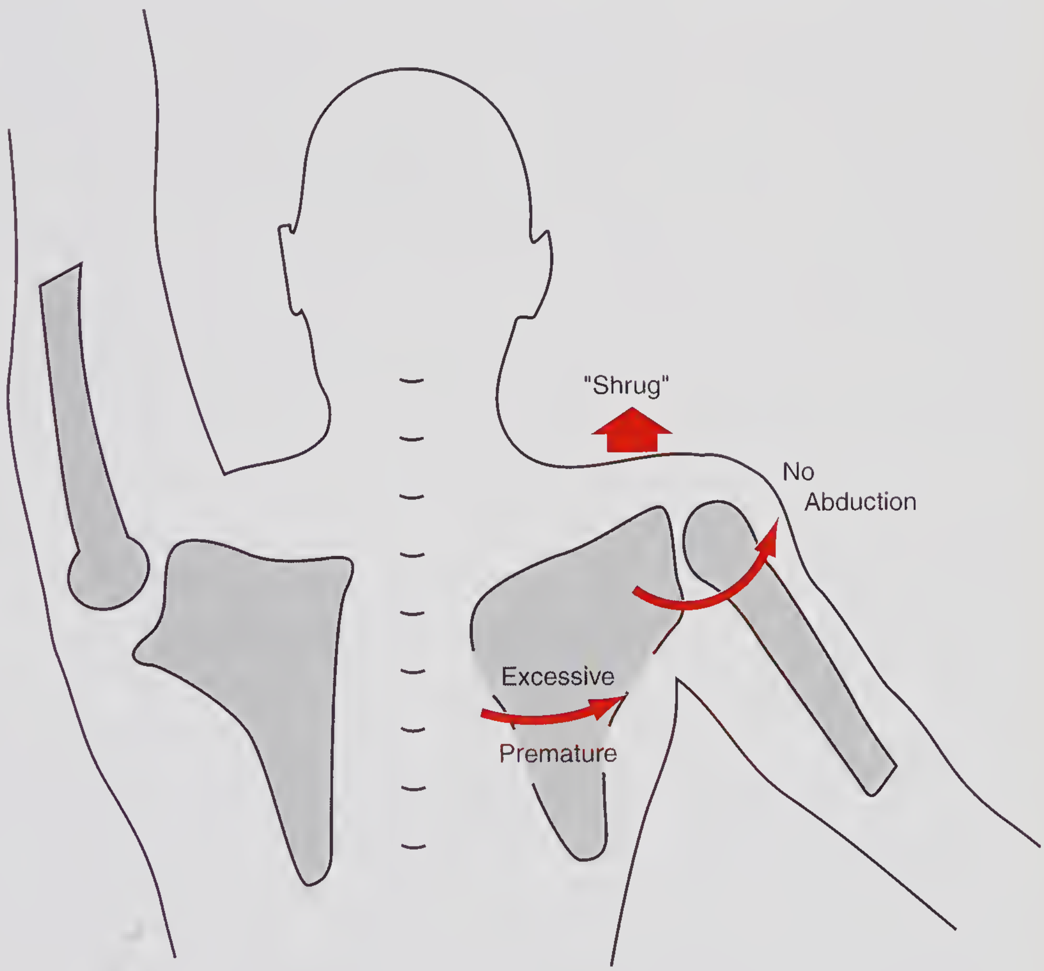


FIGURE 4.44

Shrugging Mechanism As glenohumeral motion is impaired or totally restricted, scapula begins its rotation prematurely, if not exclusively, thus causing shoulder girdle to "shrug."

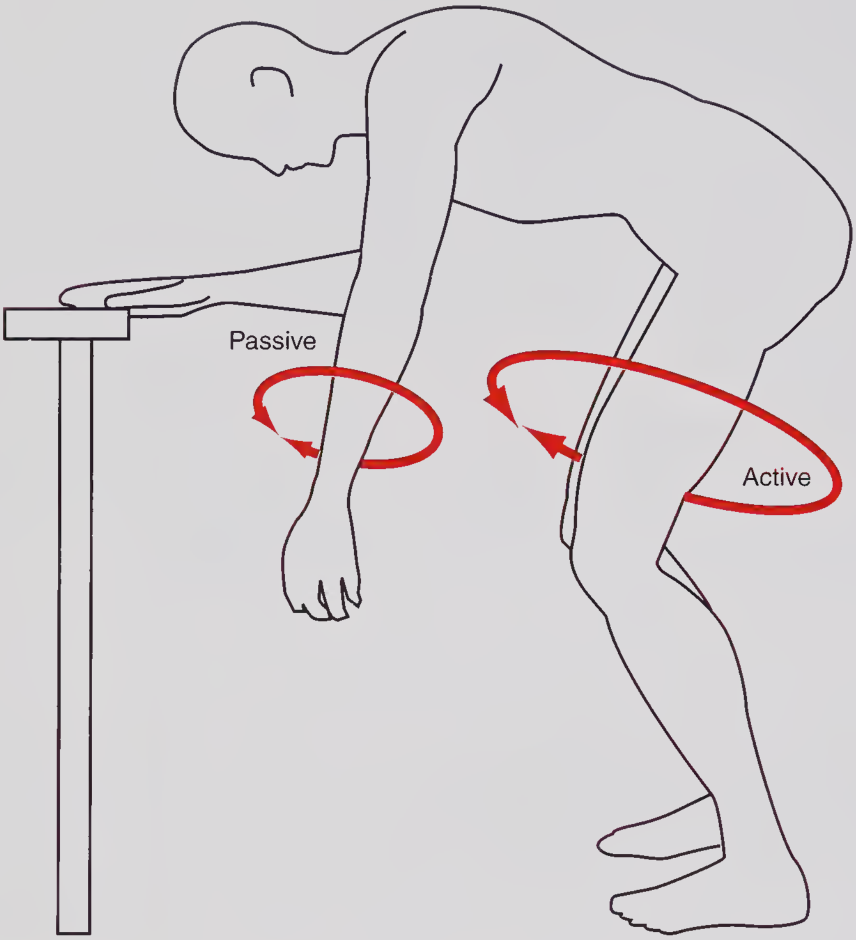


FIGURE 4.45

Codman Exercise With arm totally dependent, traction from weight of arm is applied to glenohumeral joint. Body then makes circumduction of glenohumeral joint without eliciting any muscular contraction of joint muscles.

REFERENCES

1. MacConnaill MA. Studies in the mechanics of synovial joints. *Irish J Med Sci*. 1946;21:223.
2. MacConnaill MA. The movement of bones and joints. *J Bone Joint Surg*. 1951;32:244.
3. Cailliet R. *Shoulder Pain*. 3rd ed. Philadelphia, Pa: FA Davis Co; 1991.
4. MacConaill MA. Rotatory movements and functional decalage. *Br J Phys Med*. 1950;30:5-56.
5. Kent BE. Functional anatomy of the shoulder complex: a review. *Phys Ther*. 1971;51:947.
6. Codman EA. *The Shoulder*. Boston, Mass: Thomas Todd Co; 1934.
7. Inman V, Saunders M, Abbott IC. Observations on the function of the shoulder joint. *J Bone Joint Surg*. 1944;36:1-30.
8. Jones L. The shoulder joint. *Calif Med*. 1956;84:185-192.
9. Freedman L, Munro R. Abduction of the arm in the scapular plane: scapular and glenohumeral movements. *J Bone Joint Surg Am*. 1966;48:1503-1510.

chapter 5

Functional Anatomy of the Elbow, Wrist, Hand, and Fingers

THE ELBOW

The elbow consists of 3 articulations: humeroulnar, capitular radiohumeral, and radioulnar joints (Figure 5.1). The humeroulnar joint permits flexion and extension, and the capitular radial and radioulnar joints permit pronation and supination of the forearm (Figure 5.2).

The elbow joint is stabilized by 2 major collateral ligaments: an anterior and a posterior band. The anterior ligament arises from the medial aspect of the ulna and the radius. The posterior ligament is thinner and restricts motion of the elbow when the elbow is flexed to an angle greater than 90 degrees (Figure 5.3).

These 3 muscles act on the elbow:

1. The brachial muscle, which originates from the lower half of the humerus and attaches to the anterior aspect of the coronoid process. It is the major flexor of the elbow. The brachialis is innervated by the musculocutaneus nerve (C5, C6, and C7 roots).
2. The long and short heads of the biceps, which unite about the middle of the humerus and insert on the medial aspect of the radius. These muscles flex but predominantly supinate the forearm. The biceps muscles are innervated by the musculocutaneus nerve (C5, C6, and C7 roots).
3. The triceps, which originates from the lower posterior aspect of the humerus and inserts on the ulna. This muscle extends the arm. Its nerve supply is the radial nerve (C5, C6, C7, C8, and frequently T1 roots).

Forearm muscles originating from the elbow region include the flexor carpi radialis, palmaris longus, flexor digitorum superficialis, 1 head of the pronator teres, extensor carpi radialis brevis, extensor digitorum, extensor digiti minimi, extensor carpi ulnaris, and anconeus. All these muscles activate the wrist and fingers and are secondarily active at the elbow articulation. They originate from the epicondyles (Figures 5.4, 5.5).

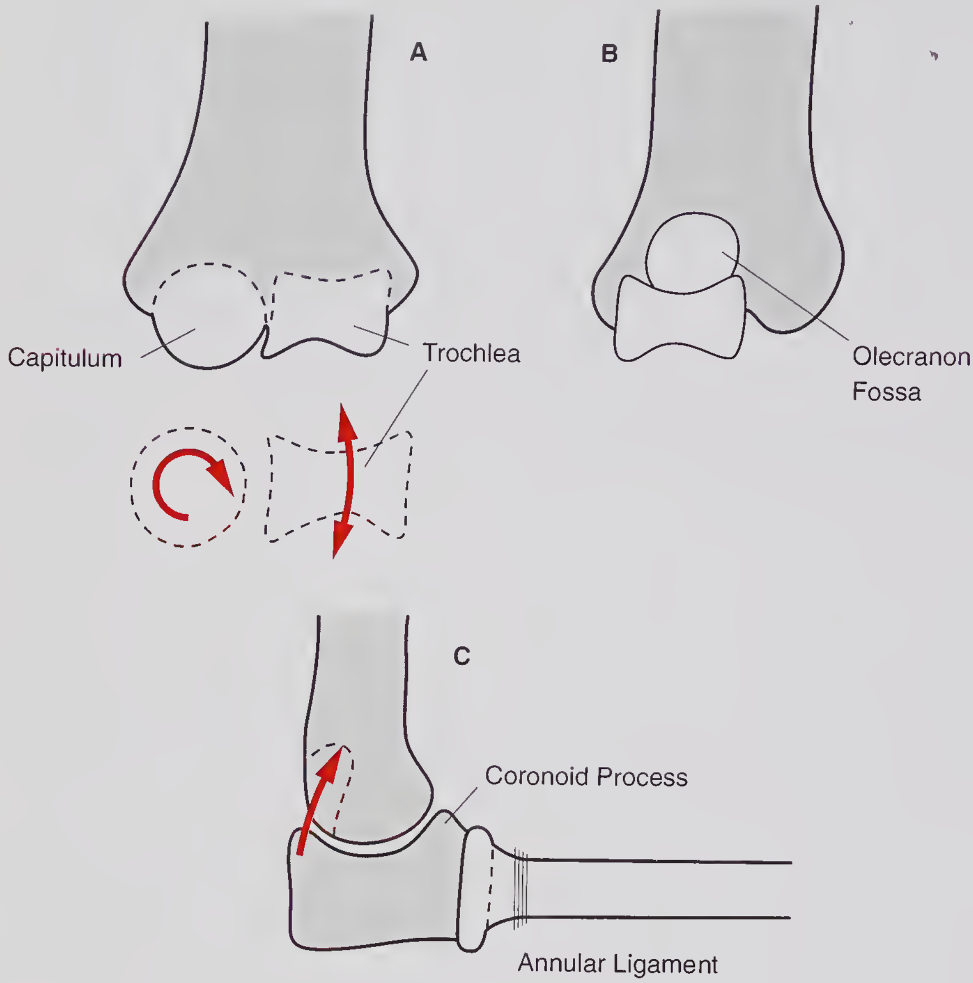


FIGURE 5.1

Bony Anatomy of Elbow A, Anterior view depicting round sphere of capitulum, upon which rotates radius. Trochlea is spoon-shaped, about which ulna flexes and extends. B, Posterior view of humerus showing olecranon fossa, into which posterior olecranon enters in extension of elbow. C, Lateral view of elbow.

The anterior aspect of the elbow joint, called the *antecubital fossa*, contains the biceps tendon, the radial and brachial arteries, the median and ulnar nerves, and the origin of many of the forearm muscles.

Many nerves are located near the elbow joint. The ulnar nerve is superficial in the olecranon fossa and is exposed to direct pressure, trauma, or both. The nerve passes through a groove behind the medial condyle and is covered by a fibrous sheath. It forms the cubital tunnel. The nerve enters the forearm between the 2 heads of the ulnar flexor muscle (Figure 5.6).

The radial nerve branches into the region of the elbow as it descends into the forearm, where it proceeds in front of the lateral condyle of the humerus between the brachial and brachioradialis muscles. Below the elbow joint, it passes under the origin of the short radial extensor muscle. This muscle originates from a fibrous band that stretches from the epicondyle to the deep fascia of the volar surface of the forearm (Figures 5.7, 5.8).

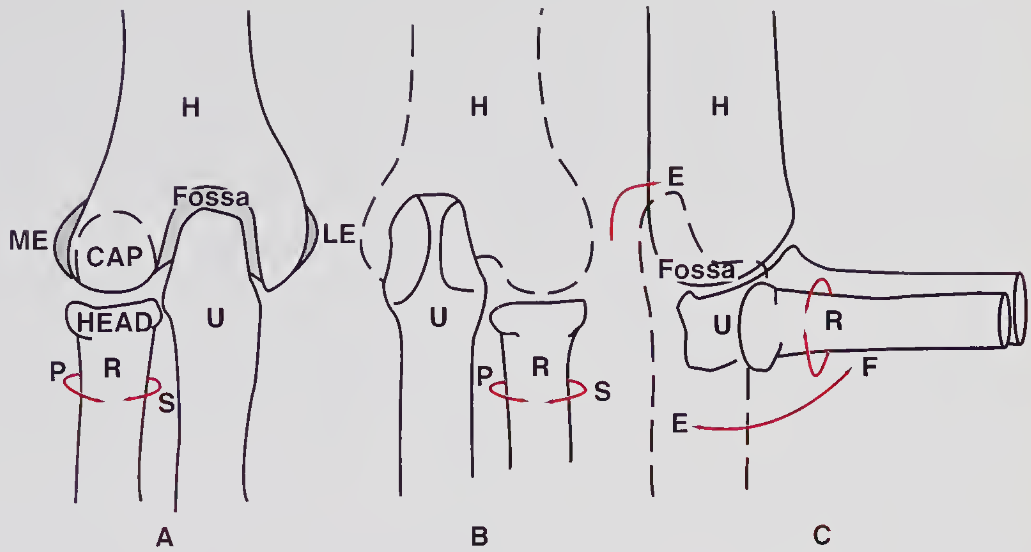


FIGURE 5.2

Functional Anatomy of Elbow Joints A, Rotation of radial (R) head: pronation (P) and supination (S). B, Ulna (U) in full extension and inserted into fossa of humerus (H). C, Flexion of elbow (F) and in dotted lines extension (E). ME indicates medial epicondyle; LE, lateral epicondyle.

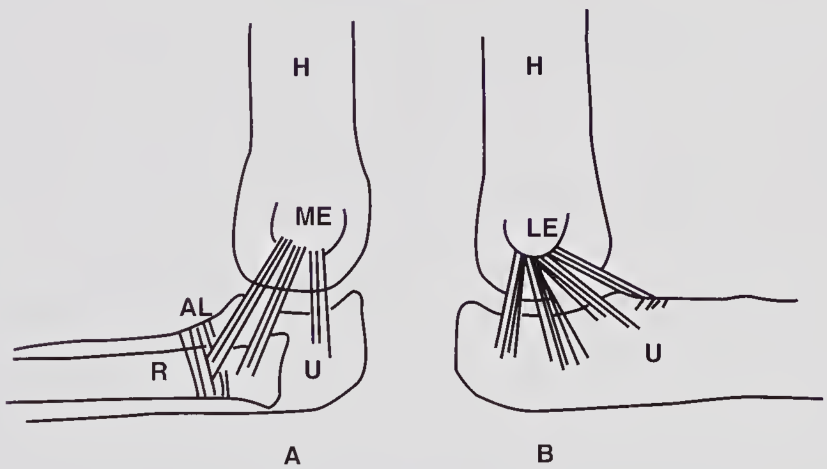


FIGURE 5.3

Collateral Ligaments of Elbow Joints A, Collateral ligaments originating from medial epicondyle (ME) of humerus (H) and attaching to radius (R) and annular ligament (AL). B, Lateral collateral ligament originating from lateral epicondyle (LE) and attaching to ulna (U).

The superficial branch passes to the outside, and the deep branch descends and continues distally to penetrate the supinator muscle through a small slit. This deep branch ultimately becomes the posterior interosseous nerve. The superficial branch is sensory to the area over the muscles called the "snuffbox," which is located between the first and the second metacarpal. (Refer to Figure 5.34 later in this chapter for an illustration of the "snuffbox.")

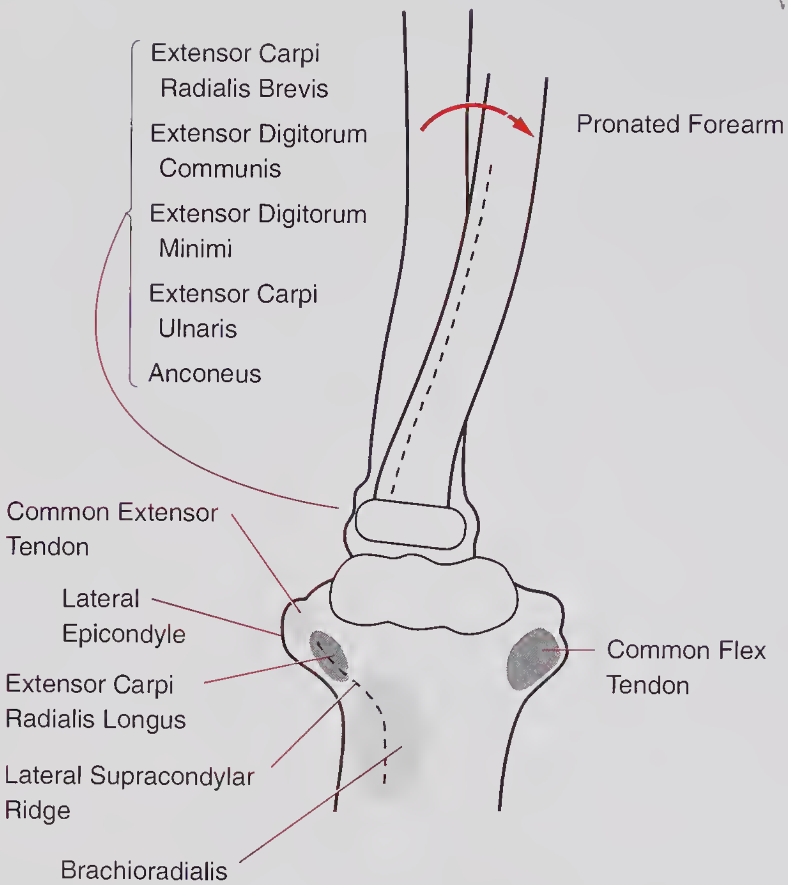


FIGURE 5.4

Bony Aspect of Elbow Origin sites of forearm muscles, with left forearm pronated (viewed from above).

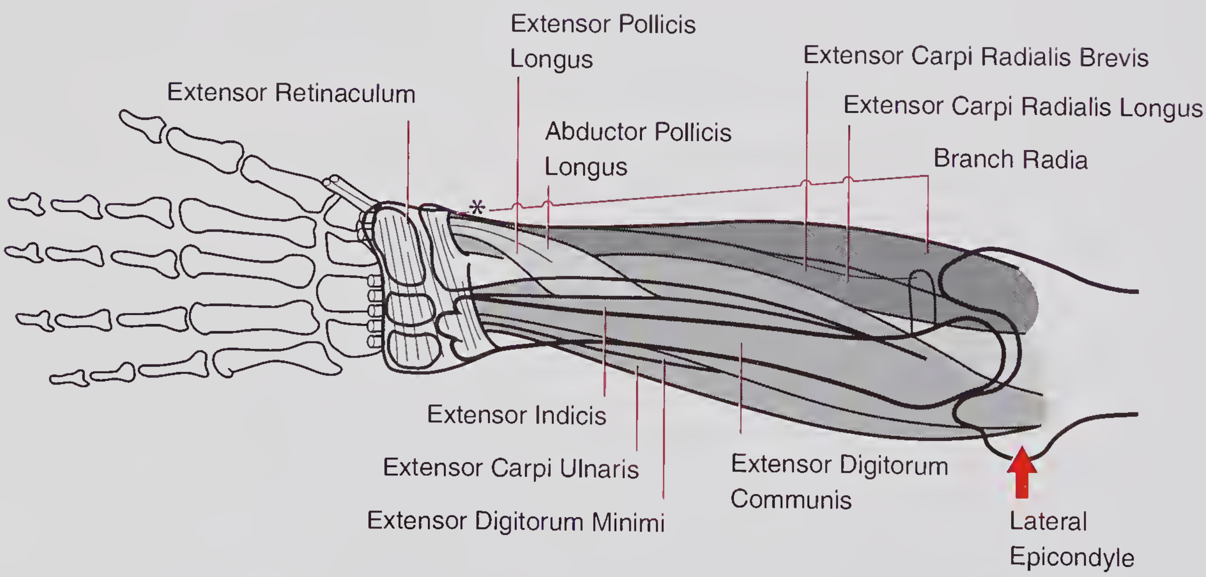


FIGURE 5.5

Extensor Aspect of Forearm Muscles Extensor muscle group has its origin from lateral epicondyle. Origin and insertion of extensor muscles, as seen in left arm. Asterisk indicates insertion sites.

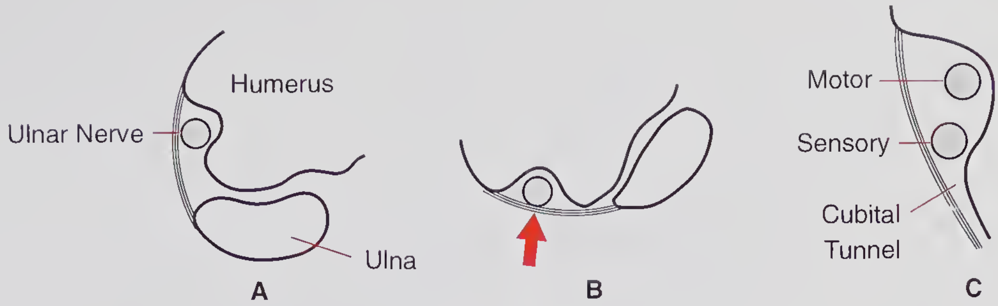


FIGURE 5.6

Cubital Tunnel A, Ulnar nerve in cubital tunnel. B, Nerve in full pronation of forearm. C, Anatomical division of ulnar nerve in motor and sensory fibers.

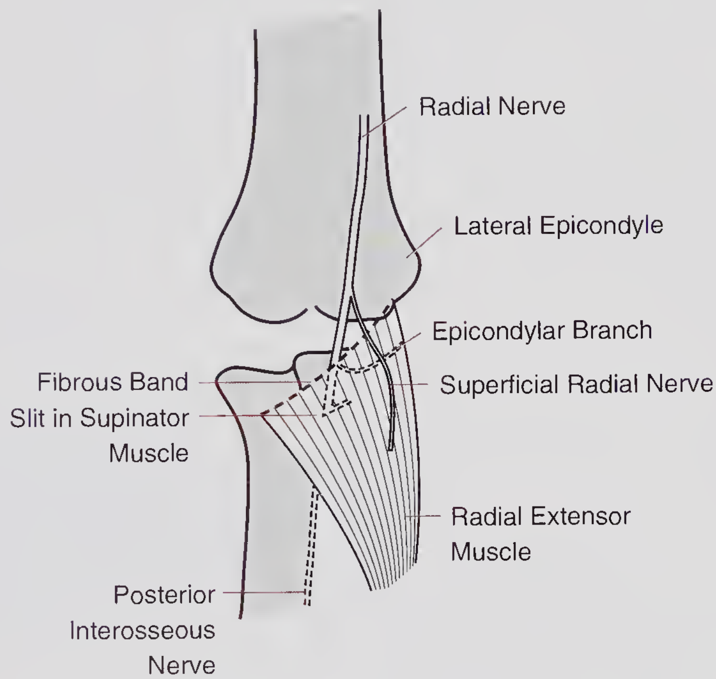


FIGURE 5.7

Deep Branch of Radial Nerve Deep branch of radial nerve passes under fibrous band that is origin site of musculus extensor carpi radialis longus (ECRL). Superficial radial nerve branches just cephalad to band.

The median nerve (C6, C7, C8, and Tl) descends the upper arm and enters the forearm by passing between the ulnar and humeral heads of the round pronator muscle (pronator teres); There it gives off the anterior interosseous branch (Figure 5.9).

There are, therefore, numerous structures in the antecubital space of the elbow: the radial and brachial arteries, the median and ulnar nerves, the origin of the brachial muscle, and the biceps tendon (Figure 5.10).

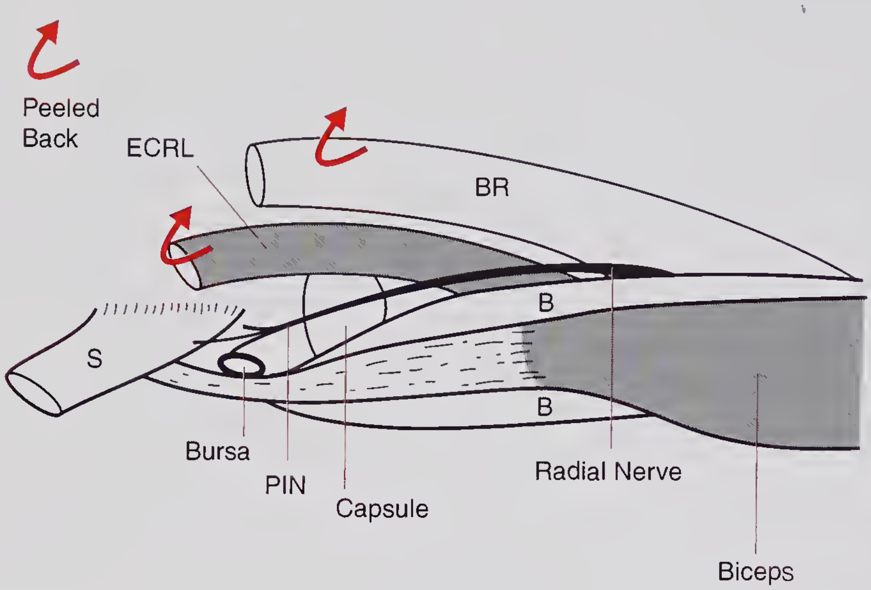


FIGURE 5.8

Radial Nerve at Elbow Course of radial nerve at elbow. Capsule of joint underlies all muscles. B indicates brachial muscle; BR, brachioradial muscle; ECRL, long radial extensor muscle (extensor carpi radialis longus); S, supinator muscle; and PIN, posterior interosseous muscle.

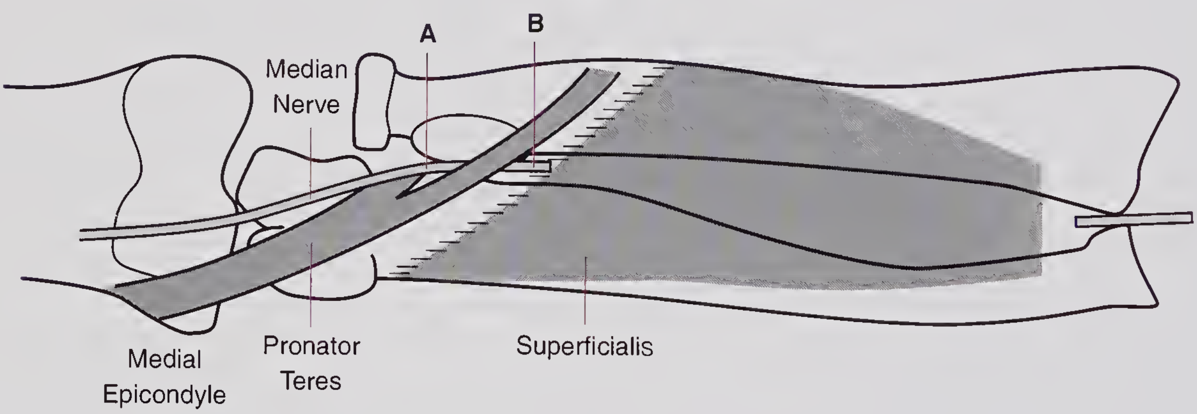


FIGURE 5.9

Passage of Median Nerve at Elbow Median nerve passes distal to elbow joint through division of musculus pronator teres (A–B), then under musculus flexor digitorum superficialis.

Extrinsic Muscles

All the forearm muscles that motorize the hand and fingers traverse the wrist joint and originate at or near the elbow. The palmar group originates from the medial condyle of the humerus and is flexor in function. The group that originates from the lateral condyle of the humerus is extensor in function. The dorsal group of extensor forearm muscles is composed of superficial and deep layers, with the superficial layer divided into lateral and posterior groups. The lateral and posterior groups of the superficial layer are separated by the intrinsic muscles of the thumb. The superficial group originates from a common extensor tendon, which is attached to the

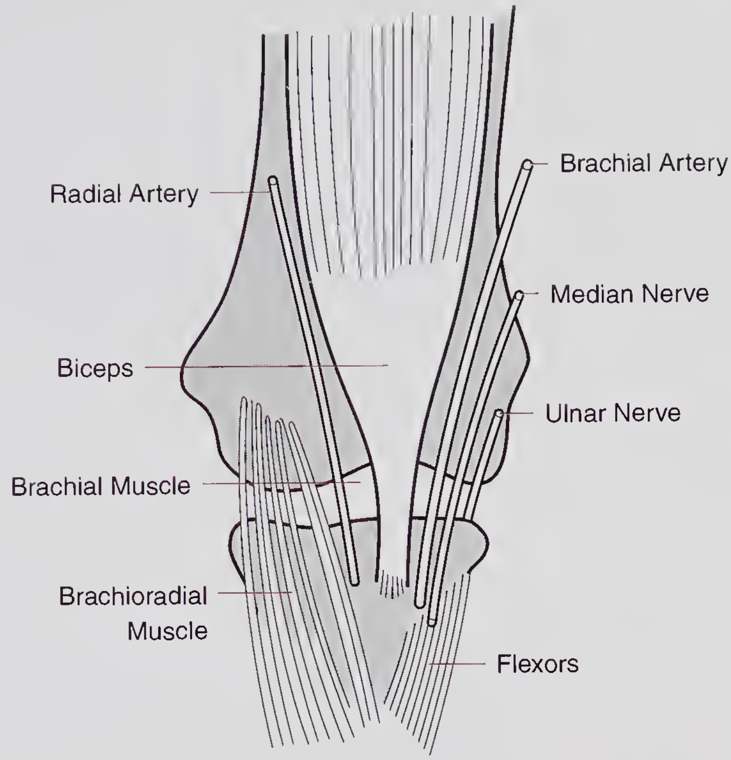


FIGURE 5.10

Content of Antecubital Fossa of Elbow Structures of antecubital fossa of elbow.

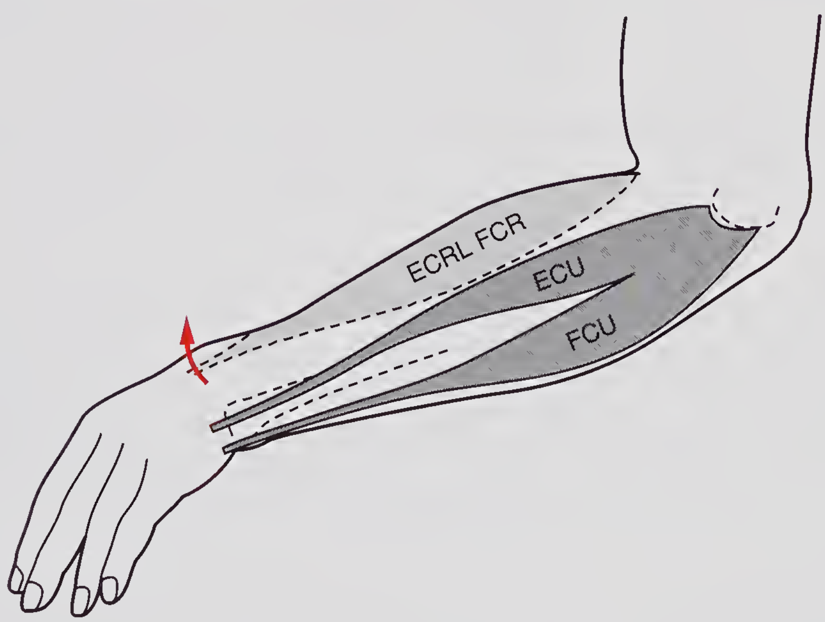


FIGURE 5.11

Origin of Extensor Muscles of Forearm Radial muscles (extensor carpi radialis and flexor carpi radialis, ECRL FCR) originate from supracondylar ridge. Ulnar muscles (extensor carpi ulnaris; ECU, and flexor carpi ulnaris, FCU) originate from lateral epicondyle.

lateral condyle area, intermuscular septum, and lateral supracondylar ridge (Figure 5.11; see also Figure 5.5 earlier in this chapter.)

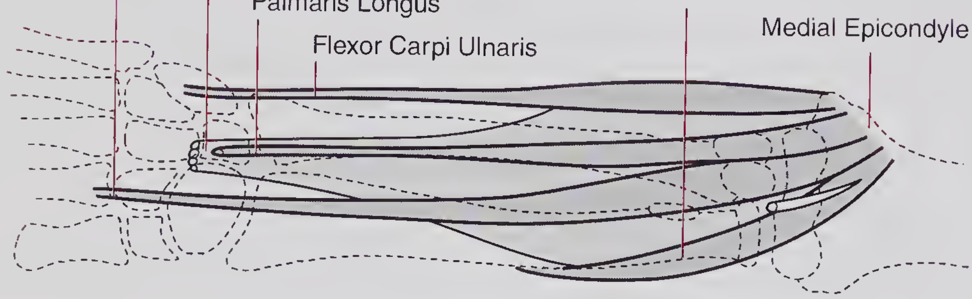


FIGURE 5.12

Origin of Superficial Palmar Group Superficial palmar muscle group originates from medial epicondyle. These muscles are flexors of wrist and fingers.

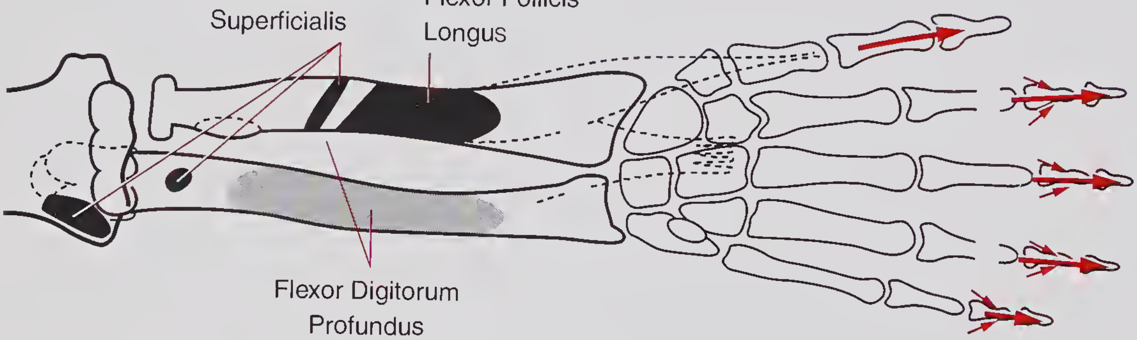


FIGURE 5.13

Origin of Flexor Muscles Flexor pollicis longus and flexor digitorum superficialis and profundus originate from midportion of radius and ulna.

The palmar flexor muscles originate from the medial condylar area of the humerus and are divided into 2 groups: superficial and deep. The superficial group originates as a common muscle mass from the medial epicondylar area, and the deep layer originates from sites on the palmar aspect of the radius and ulna (Figure 5.12). Muscles that activate the hand and fingers originate from the forearm below the elbow (Figure 5.13).

THE WRIST

The wrist joint, termed the *carpus*, is the articulation between the forearm and the carpal bones. There are 8 carpal bones situated in 2 rows. The proximal row, beginning from the thumb side, contains the navicular (scaphoid), lunate, triquetral, and pisiform bones. The latter is anterior to the os triquetrum. The proximal row includes the radius and the ulna of the forearm. The radial styloid process is lateral on the thumb side, and the ulna is on the side of the little finger (Figures 5.14, 5.15).

The radial styloid reaches further forward than does the ulnar styloid, although in many people both are equal. The articular surface of the radius

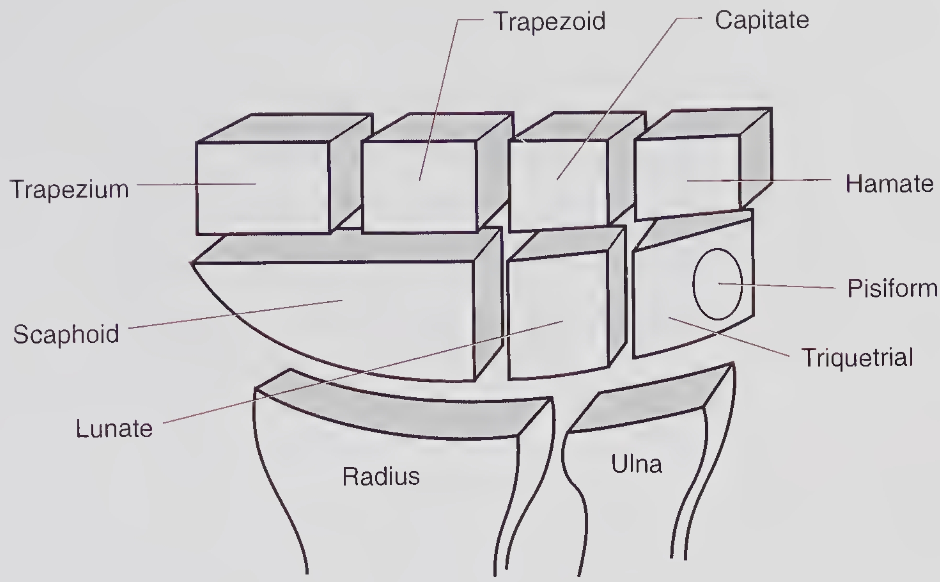


FIGURE 5.14

Bones Forming Wrist Carpal bones and radius and ulna forming wrist are shown schematically.

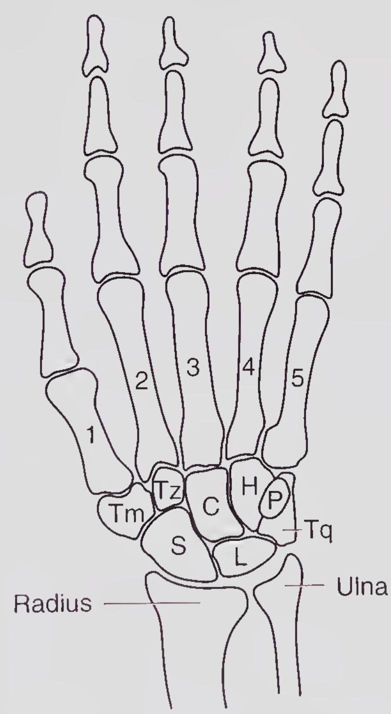


FIGURE 5.15

Bones of Hand and Wrist Bones forming hand and wrist are shown. S indicates scaphoid; L, lunate; Tq, triquetral; P, pisiform; H, hamate; C, capitate; Tm, trapezium and Tz, trapezoid.

is on an oblique plane. The dorsal surfaces of the radius and the ulna protrude further forward than does the palmar surface (Figure 5.16).

The distal end of the radius is concave and articulates with the convex surface of the proximal carpal row. This forms an incongruous joint, in that

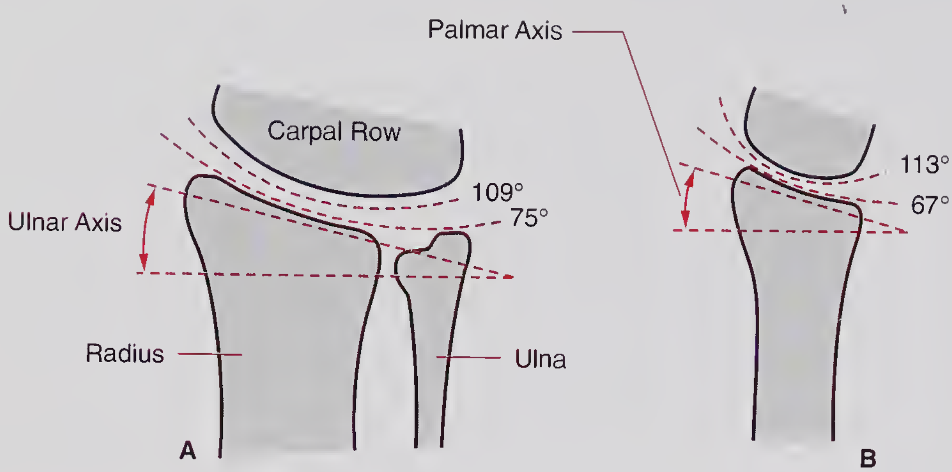


FIGURE 5.16

Relationship of Carpal Row to Radioulnar Surface A, Radial margin of radius protruding further than ulnar margin. Joint is in an oblique direction (ulnar axis). Concavity of radius-ulna margin is 75 degrees and that of carpal margin 109 degrees, forming an incongruous joint. B, Lateral view of dorsal protrusion forming palmar axis. Margins are also incongruous, with radial margin at 67 degrees and carpal margin at 113 degrees.

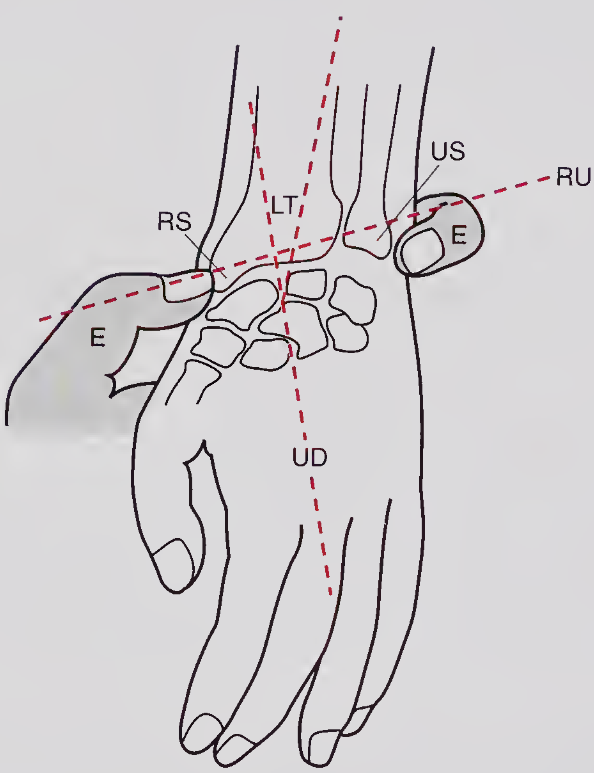


FIGURE 5.17

Obliquity of Radial Ulnar Styloids: Resting Hand Radial styloid (RS) protrudes further distally than does ulnar styloid (US), forming oblique radial-ulnar line (RU). Examiner (E) manually determines this. This obliquity determines resting hand to be slightly ulnar and palmar deviated (UD). LT indicates Lister tubercle, which is palpable.

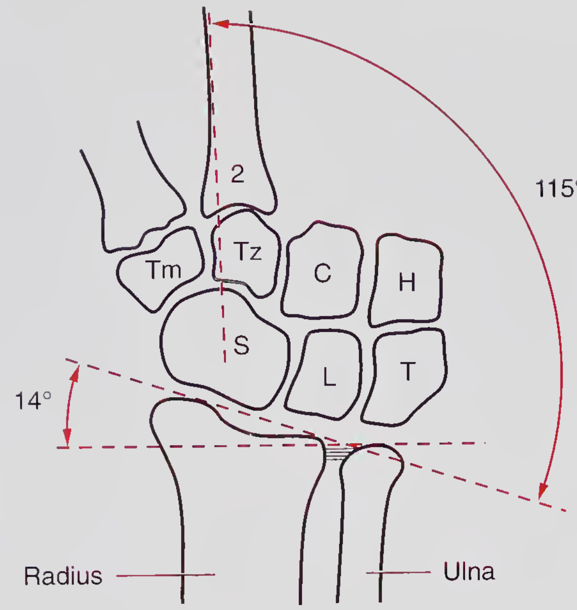


FIGURE 5.18

Ulnar Deviation Wrist has 15-degree ulnar deviation. Second metacarpal is in direct alignment with wrist, which is 115-degree deviation from plane of radial and ulnar bones of wrist. S indicates scaphoid; L, lunate; H, hamate; C, capitate; Tm, trapezium; and Tz, trapezoid.

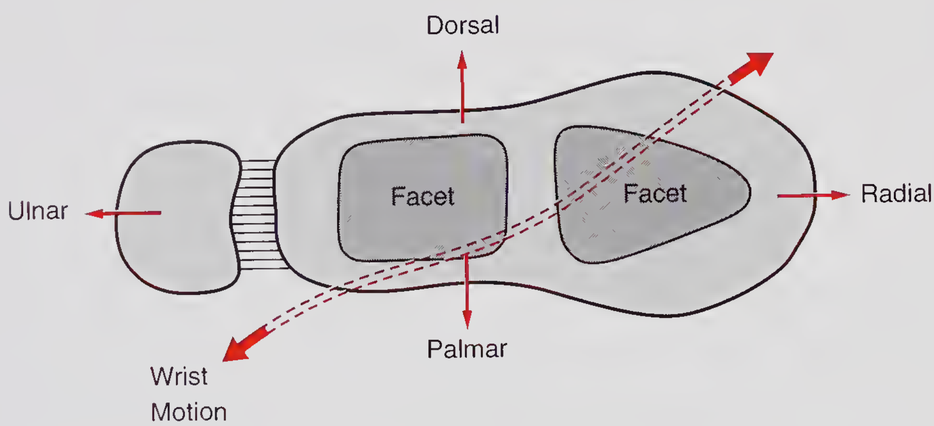


FIGURE 5.19

Facets of Doral Surface of Radius Wrist moves in oblique manner of carpals on facets of radius.

the articulating surfaces are of a different curvature. The radioulnar surface is less concave than the convex surface of the proximal carpal row. The hand at rest resides in a slightly ulnar and palmar position (Figures 5.17, 5.18).

There are 2 facets on the distal surface of the radius. The scaphoid bone glides on the triangular radial facet, and the lunate glides on the cuboid facet. Wrist movements are oblique, with the carpal row gliding on the cartilage of the radial surface (Figures 5.19, 5.20, 5.21).

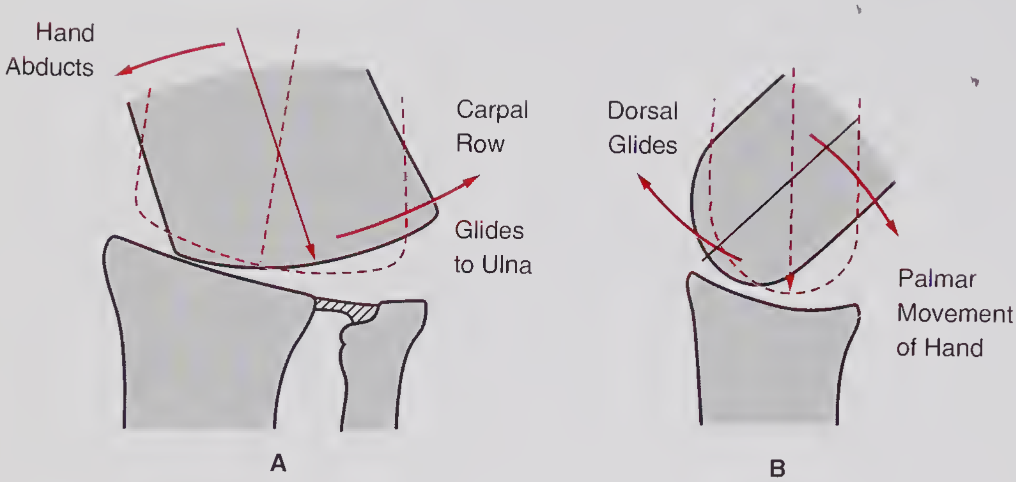


FIGURE 5.20

Carpal Movement A, When hand moves radially, carpal rows move in opposite (ulnar) direction. Capitate glides ulnarly and "toward" proximal row, to pack tightly. B, In ulnar movement, opposite occurs.

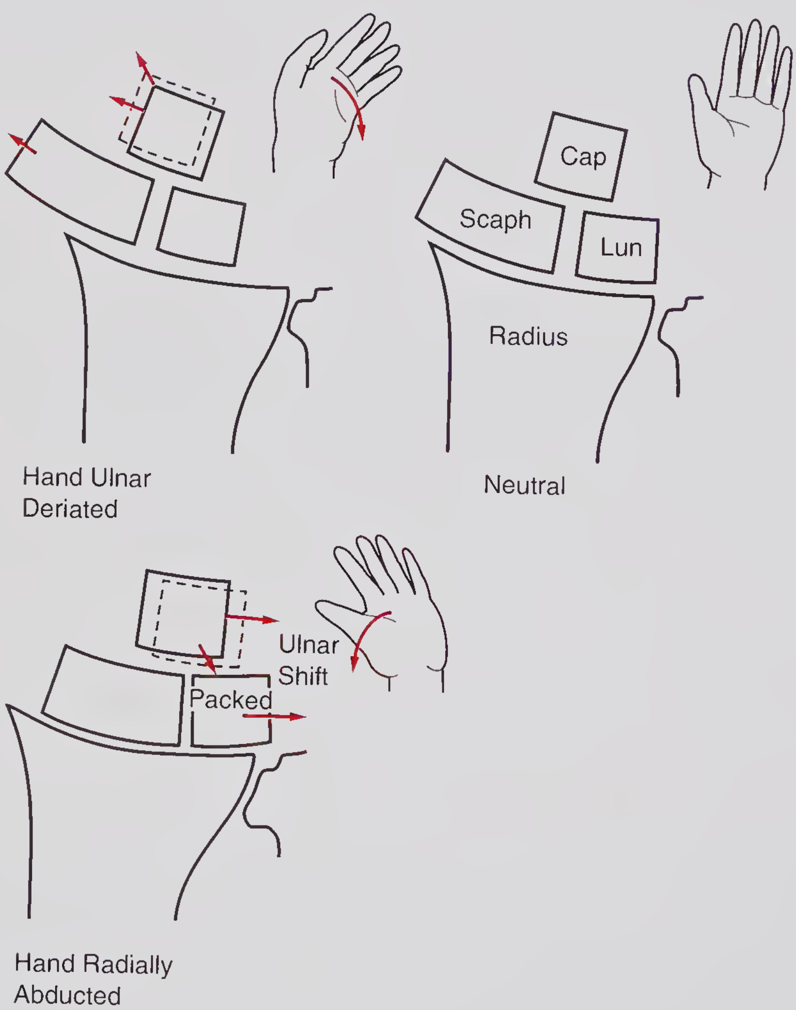


FIGURE 5.21

Gliding Motion of Radiocarpal Articulation Motion between radial surface and surface of proximal carpal row is that of gliding. Carpal rows glide in direction opposite from movement of hand. This gliding is permitted by capsular and ligamentous laxity. Scaph indicates scaphoid; Lun, lunate; and Cap, capitate.

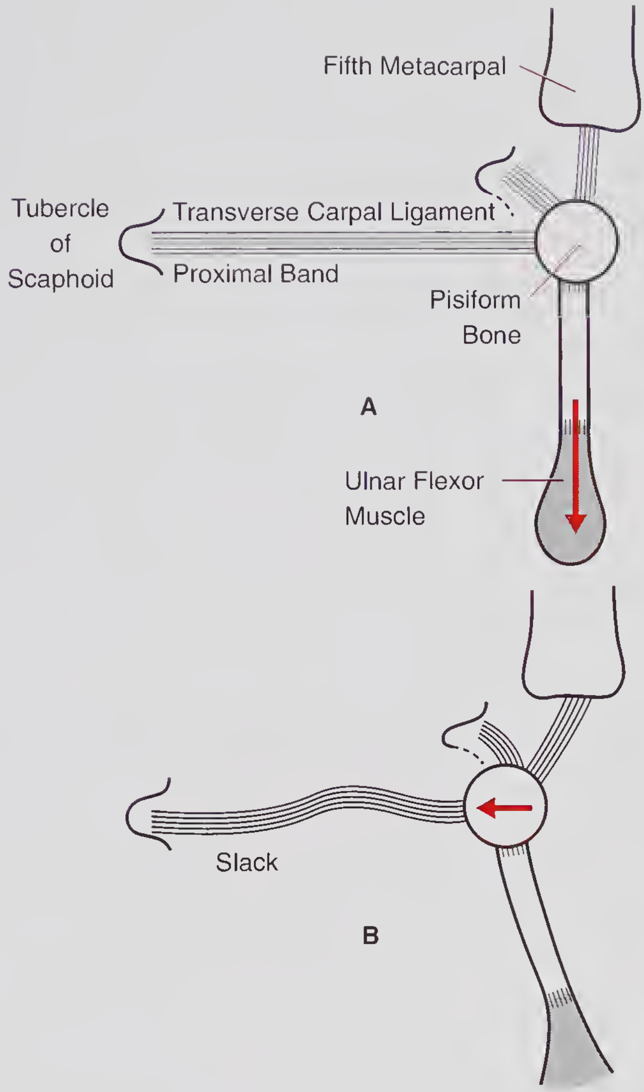


FIGURE 5.22

Ligaments of Pisiform Bone Proximal band of transverse carpal ligament attaches from scaphoid tubercle to pisiform bone. A, It becomes taut dependent on action of ulnar flexor muscle of wrist, in which it is essentially sesamoid bone. B, With ulnar flexor muscle slack, ligaments of pisiform bone also become slack.

Ligaments of the Wrist

The ligaments of the hand that furnish support, yet permit movement, are the longitudinal radial and ulnar ligaments plus the transverse and oblique ligaments. The ulnar collateral ligaments arise from the ulnar styloid process and the triangular ligament attaching to the pisiform bone (Figure 5.22). This ligament becomes taut when the hand deviates radially.

The radial collateral ligament arises from the radial styloid process, attaches to the scaphoid, and passes on to the trapezium and first metacarpal bones. It becomes taut when the hand deviates in an ulnar direction (Figure 5.23). The transverse-oblique wrist ligaments on the palmar surface maintain the carpal arch (Figure 5.24).

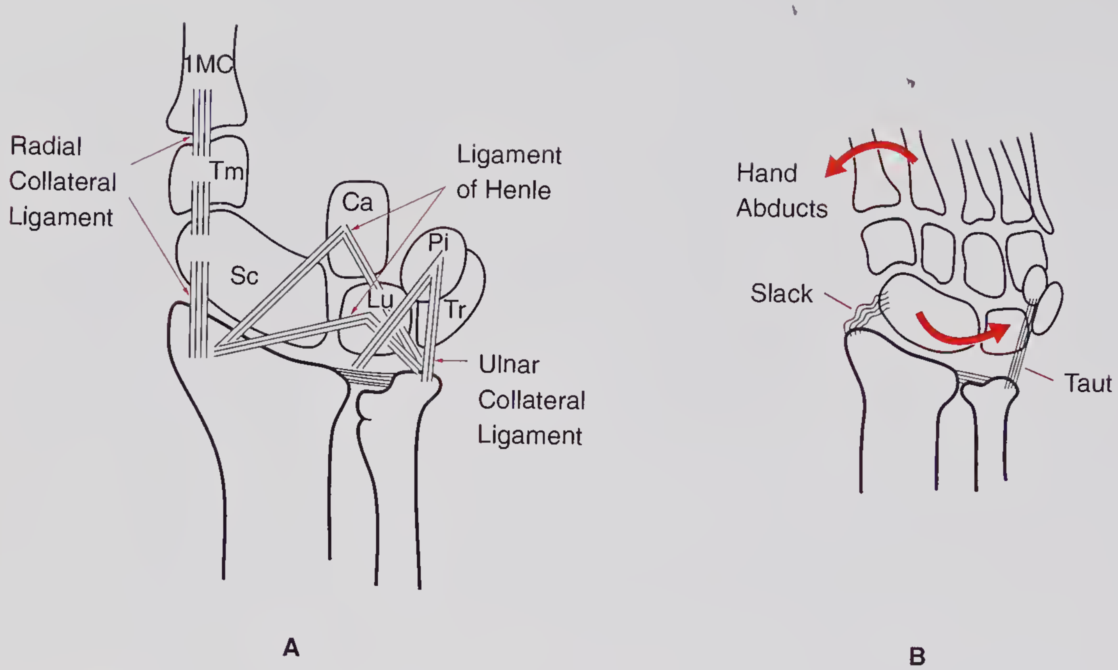


FIGURE 5.23

Ligaments of Wrist A, Ligaments of wrist. Sc indicates scaphoid bone; Lu, lunate; Tr, triquetral; Pi, pisiform; Ca, capitate; Tm, trapezium, IMC, first metacarpal. B, Action of ligaments of wrist.

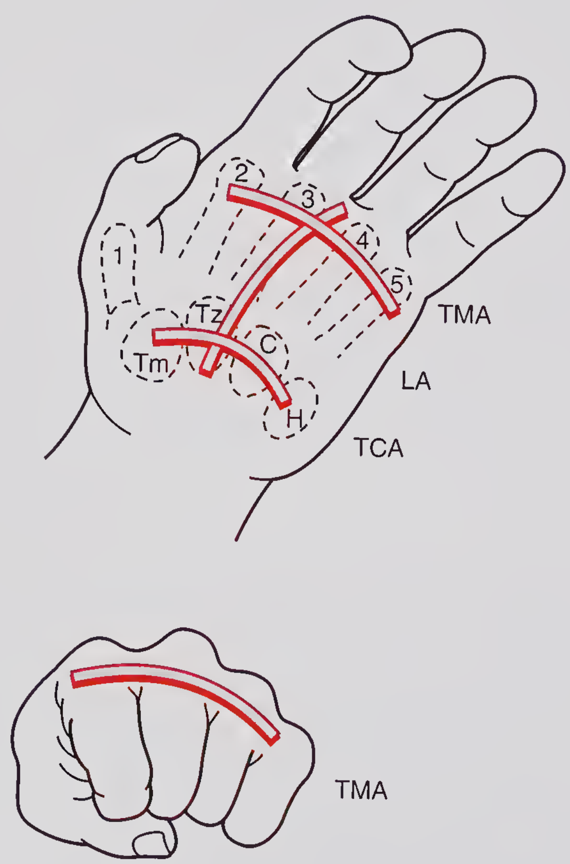


FIGURE 5.24

Arches of Hand Hand has several structural arches: transverse metacarpal arch (TMA), transverse carpal arch (TCA), and longitudinal arch (LA). Bones forming these arches are metacarpals numbered from 1 to 5, capitate (C), trapezoid (Tz), hamate (H), and trapezium (Tm).

The palmar-ulnar and palmar radiocarpal ligaments converge at the midline to attach to the lunate and capitate bones and to form the arcuate ligament of Henle. The dorsal ligaments are less symmetrical and more lax. Supination of the hand tightens the palmar ligaments, and pronation tightens the dorsal ligaments. Active and passive range of motion is a clinical determination dependent on the laxity of ligamentous structures (Figures 5.25, 5.26).

Carpal Bones

The 8 carpal bones are arranged in 2 rows. Each bone is cuboid in shape with 6 surfaces. The 4 surfaces that articulate with other carpal bones are covered with cartilage. The other surfaces, the dorsal and volar, are uncovered and roughened to permit ligamentous attachments.

The proximal carpal row contains the scaphoid, lunate, and triquetral bones. The fourth bone, the pisiform, is on the palmar surface of the os triquetrum and is considered to be a sesamoid bone in the tendon of the ulnar flexor muscle. The proximal row articulates with the radius and the ulna, to form the wrist joint.

The distal row contains the trapezium (greater multangular), trapezoid (lesser multangular), capitate, hamate bones. The distal margin of the proximal row is concave and articulates with the convex margin of the distal row. The trapezium and trapezoid bones articulate with the scaphoid, capitate, and lunate bones, and the hamate articulates with the triquetral bone. No carpal bone articulates with the ulna.

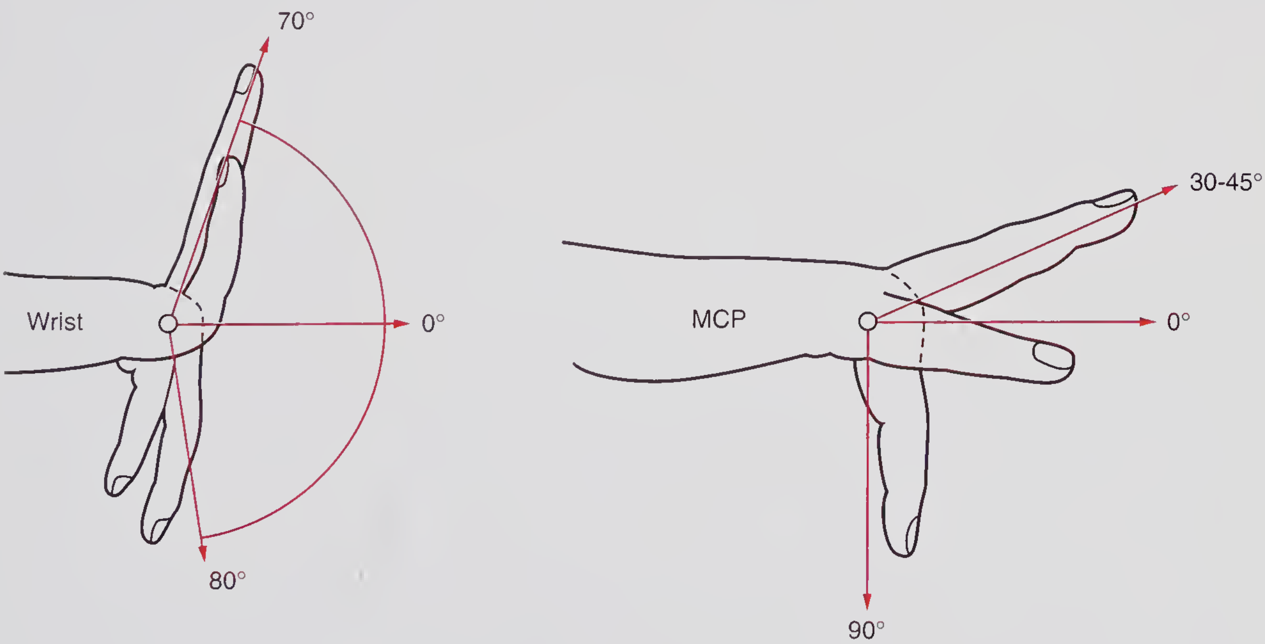


FIGURE 5.25

Measurement of Wrist Range of Motion Average range of motion of wrist is 70 degrees extension and 80 degrees flexion. Range of motion at metacarpophalangeal joints (MCP) are 30 to 45 degrees extension and 90 degrees flexion.

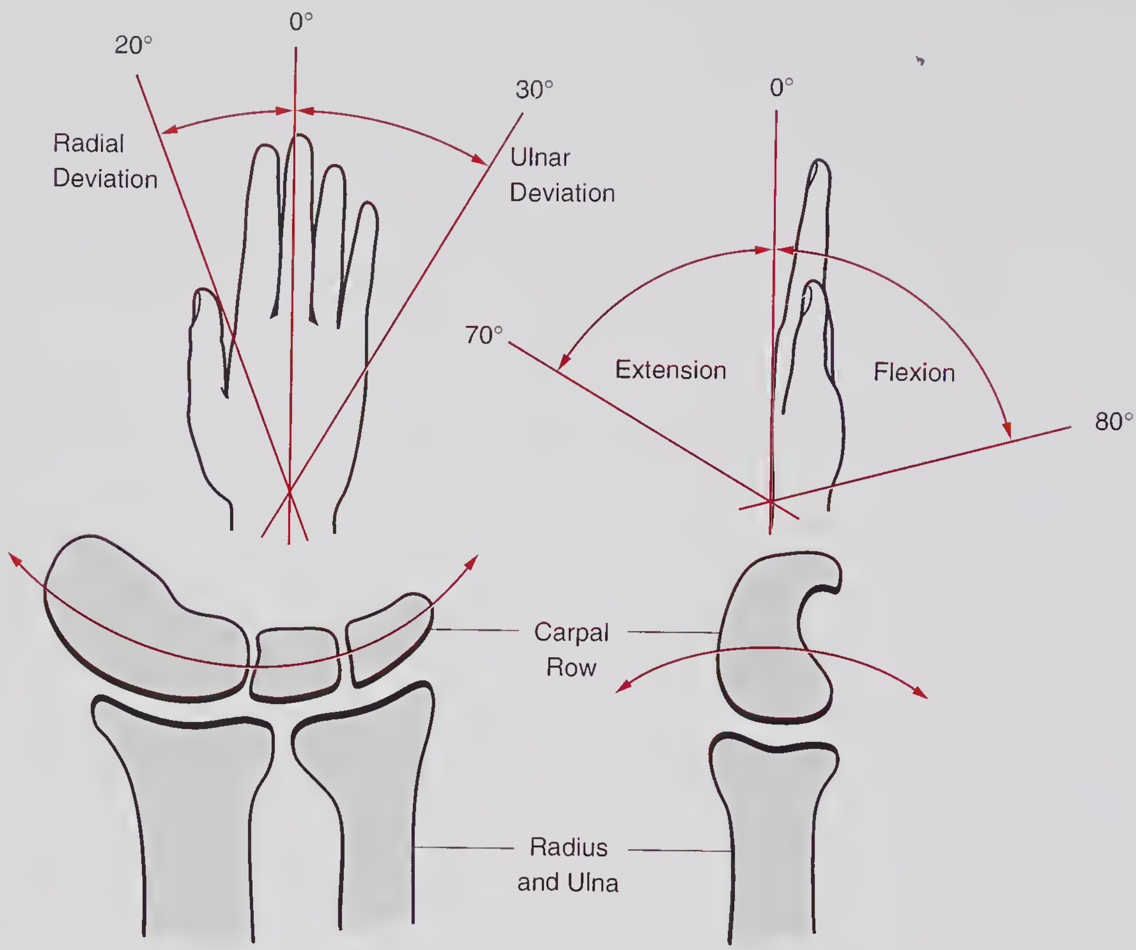


FIGURE 5.26

Measurements of Radial and Ulnar Deviation of Wrist Wrist deviates radially to 20 degrees and ulnarly to 30 degrees. Extension to 70 degrees and flexion to 80 degrees are considered average.

The carpal bones are closely "packed," meaning that each surface is symmetrical to the opposing surface and is reinforced by the intercarpal ligaments (Figure 5.27).

The palmar arch is maintained by the transverse carpal ligament, which is attached to the tubercle of the navicular bone and extends to the pisiform bone. As the pisiform bone is essentially a sesamoid bone within the ulnar flexor tendon, it can be relaxed yet taut when the muscle contracts, such as when the hand is held in an ulnar flexed position. The distal band of the transverse ligament is always taut, as it is attached to 2 fixed points: the tubercle of the trapezium and the hook of the hamate (Figure 5.28).

The concavity of the arched carpal bones is bridged by the transverse ligaments forming the carpal tunnel. This tunnel contains the tendons of the flexor digitorum profundus, which lie on the carpal bones and the intercarpal ligaments. It also contains the tendons of the flexor digitorum superficialis, flexor carpi radialis, and flexor pollicis longus, and the median nerve (Figures 5.29, 5.30, 5.31).

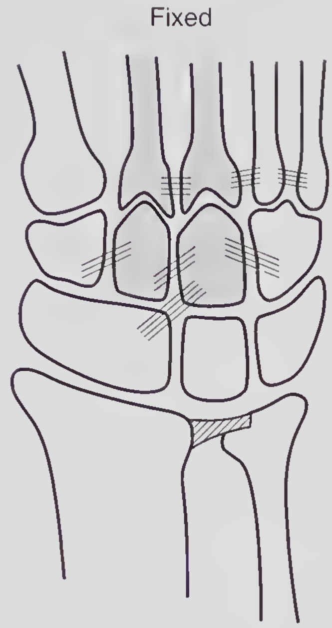


FIGURE 5.27

Intercarpal Ligaments Dorsal ligaments are related to palmar ligaments (shown) and relate to bones connected. There are few ligaments between proximal and distal carpal rows.

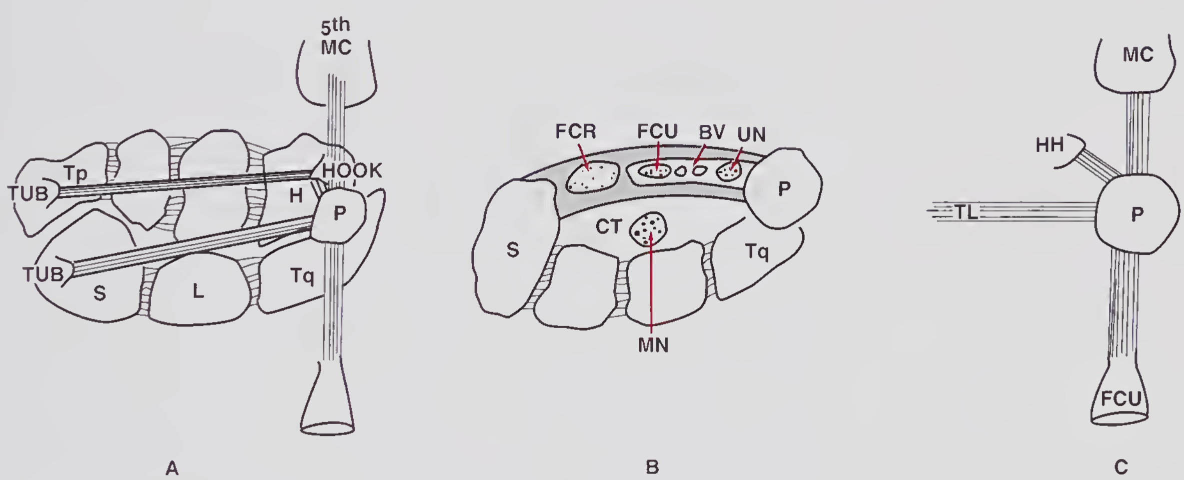


FIGURE 5.28

Transverse Carpal Ligaments The transverse carpal ligaments (TL) are also termed *flexor retinaculum* and bridge arch of carpal bones. They are formed by 2 bands—the proximal band, which extends from tubercle (TUB) of scaphoid (S) to pisiform (P), and distal band, which extends from tubercle of trapezium (Tp) to hook of hamate (H). L indicates lunate; Tq, triquetral; MC, metacarpal; CT, carpal tunnel; MN, median nerve; FCR, flexor carpal radialis; BV, blood vessels; and UN, ulnar nerve.

Cubital Tunnel

The cubital tunnel, otherwise known as Guyon canal, is a shallow trough between the pisiform bone and the hook of the hamate. Its floor is a thin layer of ligament and muscle, and its roof is the volar carpal ligament and the long palmar muscle. Its contents include the ulnar nerve, blood vessels, and the tendon of the ulnar flexor muscle of the wrist (Figures 5.32, 5.33).

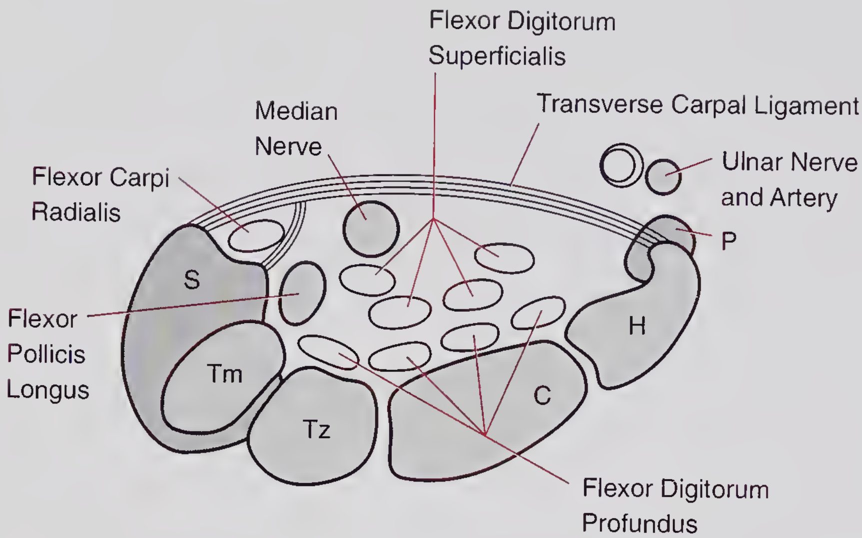


FIGURE 5.29

Contents of Carpal Tunnel Tunnel formed by carpal bones and spanning transverse carpal ligaments contain tendons of long finger flexors (deep and superficial), tendons of flexor pollicis longus and flexor carpi radialis, and median nerve. S indicates scaphoid bone; Tm, trapezium; Tz, trapezoid; C, capitate; H, hamate; and P, pisiform.

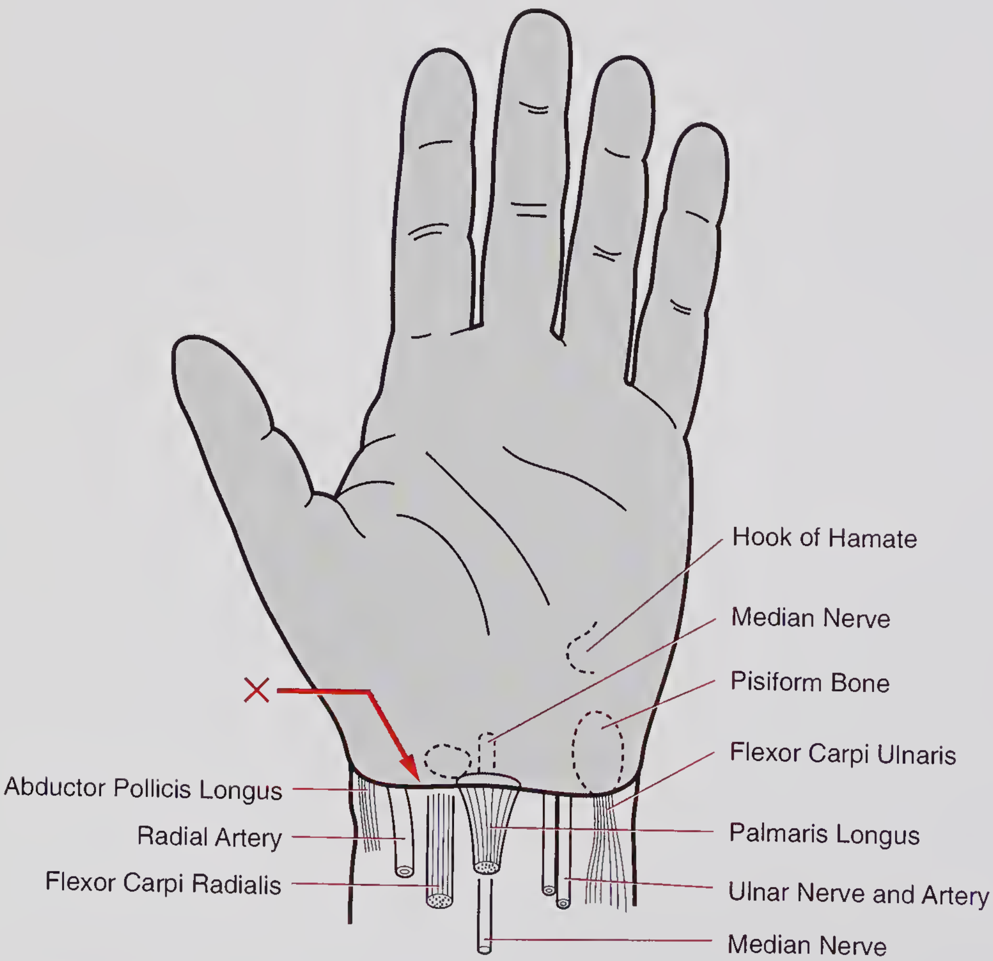


FIGURE 5.30

Superficial Landmarks at Palmar Surface of Wrist X marks crease on palmar surface of wrist, under which pass all of noted structures.

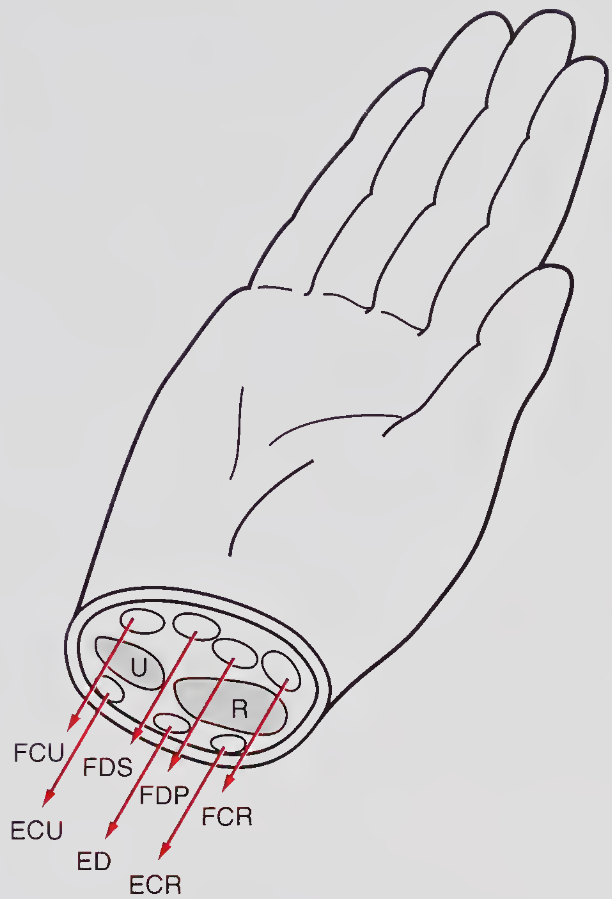


FIGURE 5.31

Cross Section of Wrist Seven tendons at wrist transmit force exerted on fingers from extrinsic muscles of forearm that pass wrist. Flexor tendons include flexor carpi radialis (FCR), flexor digitorum superficialis (FDS), flexor digitorum profundus (FDP), flexor carpi ulnaris (FCU), extensor carpi radialis (ECR), extensor digitorum (ED), extensor carpi ulnaris (ECU), ulna (U), and radius (R).

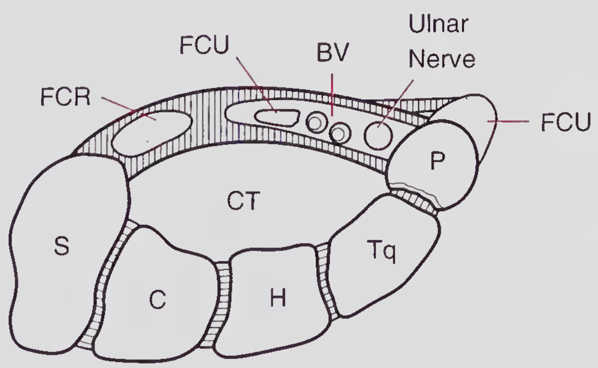


FIGURE 5.32

Guyon Canal Guyon canal is adjacent to carpal tunnel (CT) and is within flexor retinaculum. It contains ulnar nerve, tendon of ulnar flexor muscle (flexor carpi ulnaris; FCU), and ulnar artery and vein. Base of canal is scaphoid (S), capitate (C), hamate (H), triquetral (Tq), and pisiform (P) bones. FCR indicates flexor carpi radialis (radial flexor muscle); BV, blood vessel.

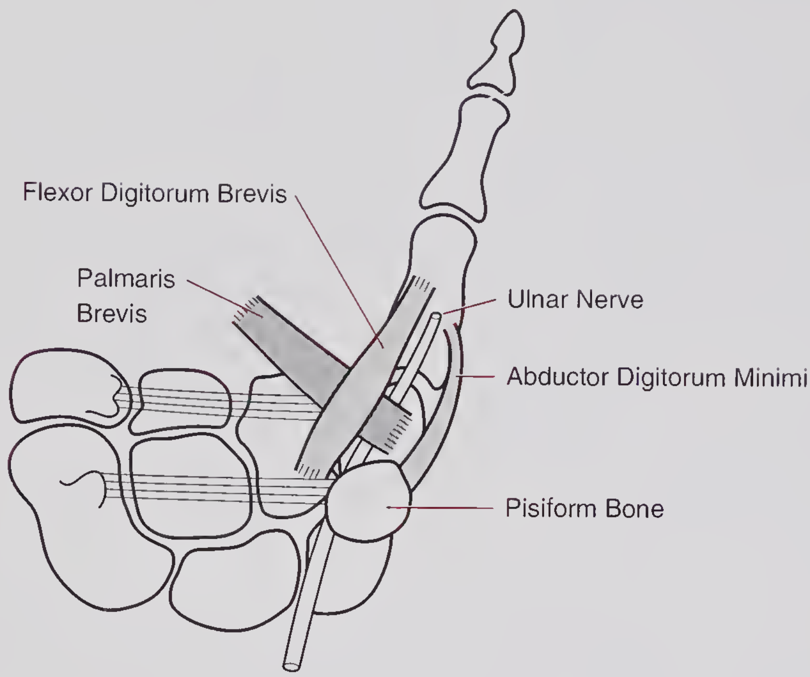


FIGURE 5.33

Entry of Ulnar Nerve Entry of ulnar nerve into Guyon canal.

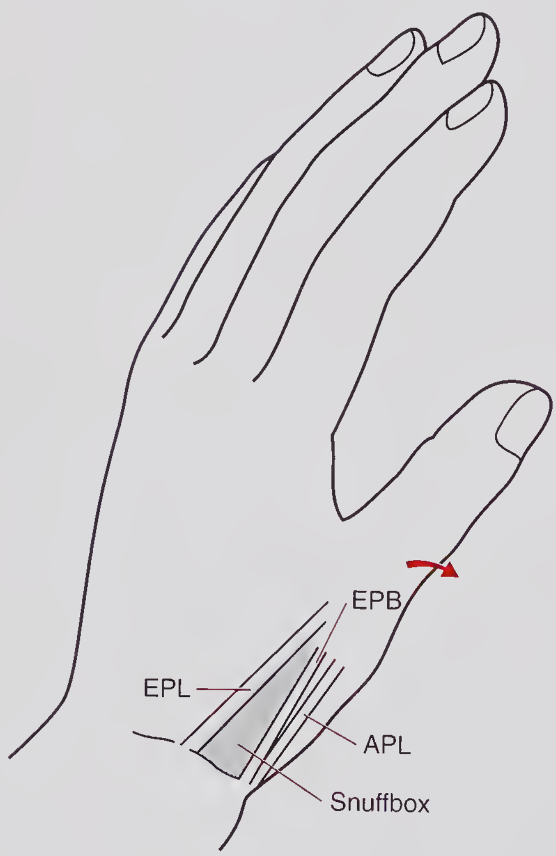


FIGURE 5.34

Snuffbox "Snuffbox" is palpable depression (shaded area) overlying navicular bone and between musculi extensor pollicis longus (EPL), extensor pollicis brevis (EPB), and abductor pollicis longus (APL). Term originated because it is area where snuff was held for inhaling.

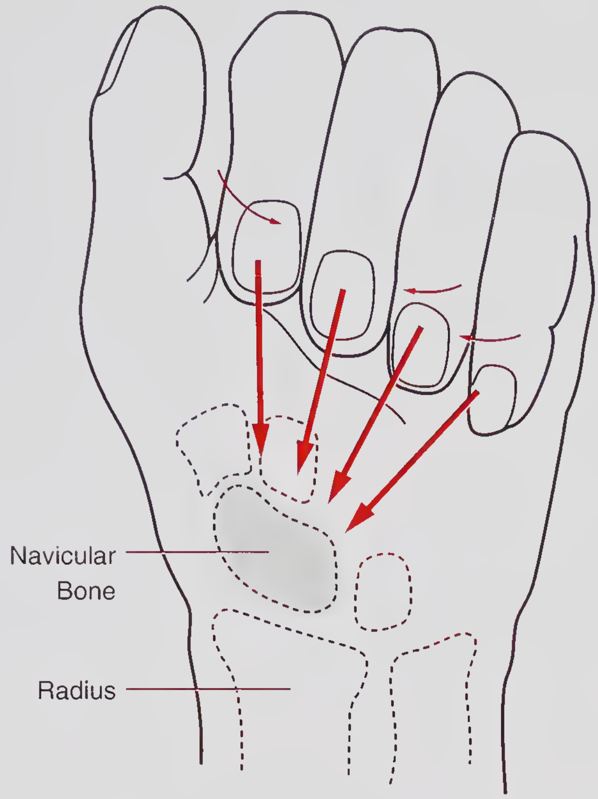


FIGURE 5.35

Finger Flexion Toward Navicular Bone Fingers normally flex across palm toward navicular bone (large arrows). Middle finger flexes and others rotate (small arrows).

Navicular (Scaphoid) Bone

The navicular bone also known as the *scaphoid* is the largest and most radial bone of the proximal carpal row. It is the floor of the "snuffbox" (Figure 5.34). The navicular bone is the point toward which all of the fingers flex (Figure 5.35).

THE HAND AND FINGERS

Metacarpal Bones

The metacarpal bones articulate with the irregular margin of the distal carpal row (Figure 5.36).

Movement of these metacarpals is intricate and varies with the individual metacarpal bone. The thumb rotates about its base in a circumduction manner, and all metacarpals move in a complex manner about their individual bases (Figures 5.37, 5.38, 5.39, 5.40, 5.41).

It is apparent that the complex movements of the total hand vary in the movements of each metacarpal and proximal phalanx. The movements depend on the articulation and the musculature, and they vary depending on the needed function and sensory feedback.

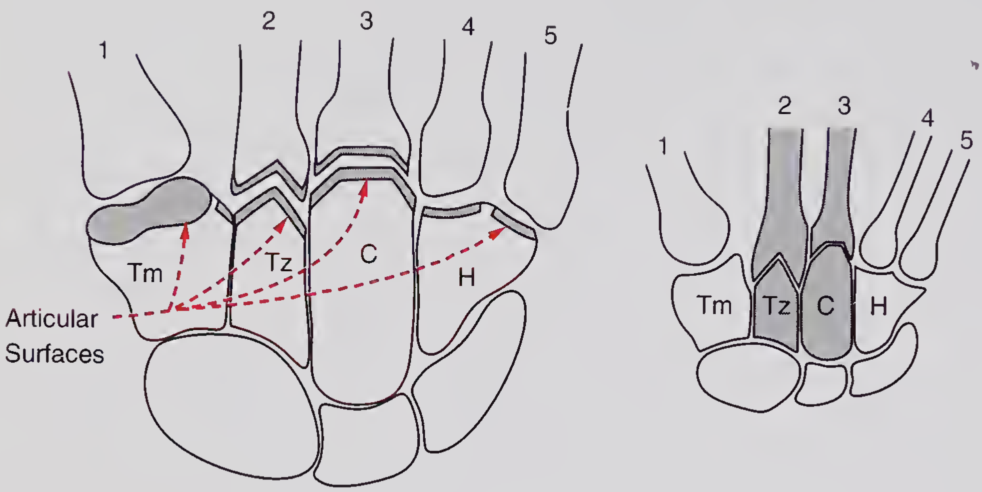


FIGURE 5.36

Carpometacarpal Articulations Five metacarpal bones articulate on 4 carpal bones of distal row. Due to configuration of carpal bones, second and third metacarpal bones are fixed on trapezoid (Tz) and capitate (C) bones. Tm indicates trapezium; H, hamate.

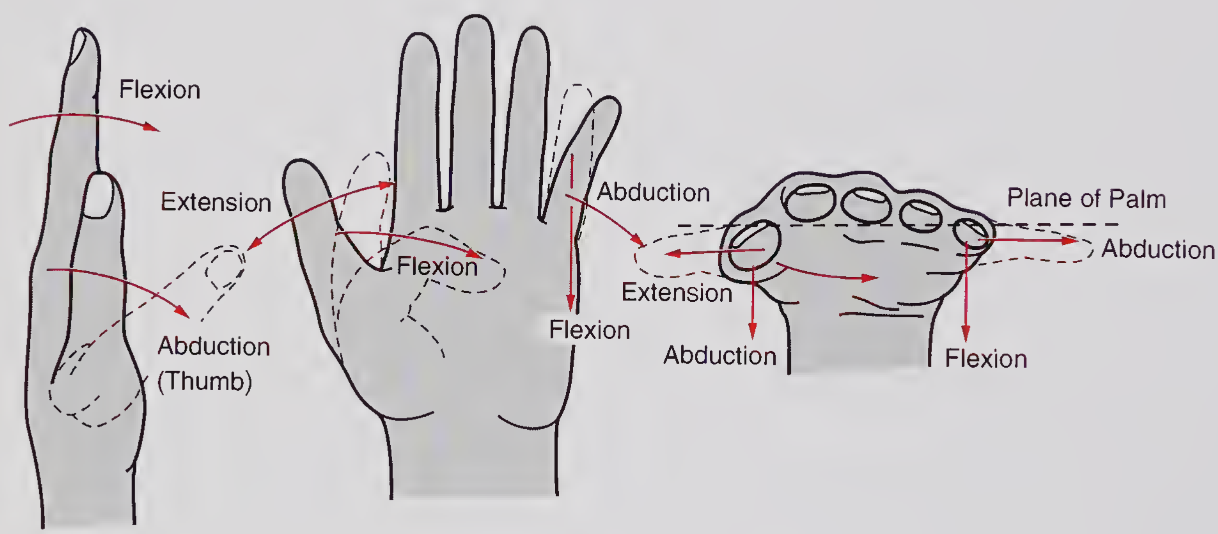


FIGURE 5.37

Movements of Metacarpal Bones In thumb, extension consists of movement away from radial side of index finger in plane of palm. Abduction is movement away from palm in 90-degree plane to that of plane of palm. Flexion is movement away from palm toward ulnar side. Abduction of thumb is perpendicular to plane of palm. Fingers 2, 3, and 4 flex toward navicular bone. In fifth finger, extension involves all digits. Abduction is away from palm along its plane. Flexion is 90 degrees of finger at metacarpophalangeal joint.

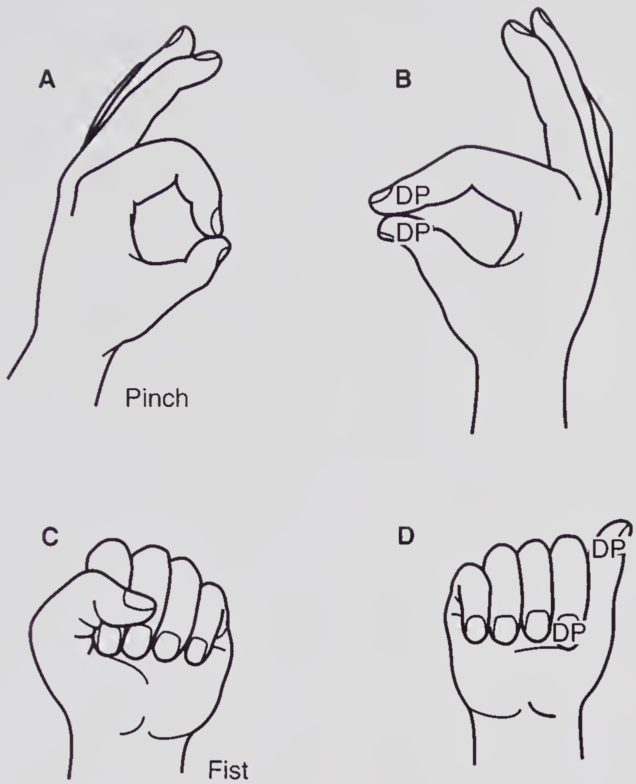


FIGURE 5.38

Pinch and Fist A and B, Pinching opposes distal phalanges (DP). C and D, Making a fist flexes all phalanges except thumb, which rotates and flexes.

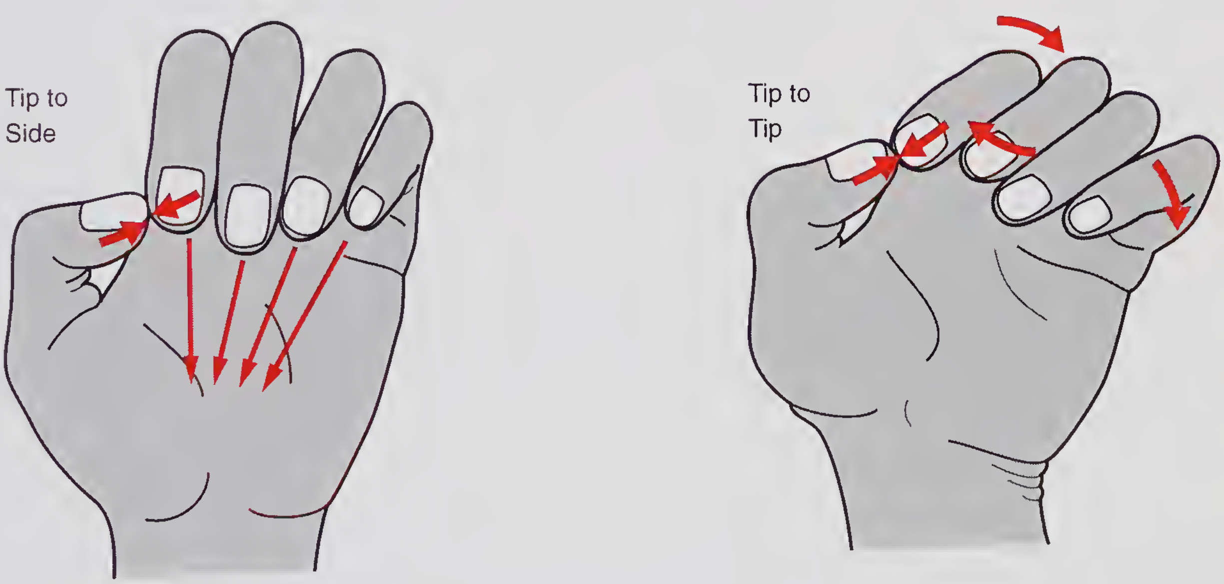


FIGURE 5.39

Tip-to-Tip and Tip-to-Side Thumb Action A, Tip of thumb to side of index finger. B, Tip of thumb to tip of index finger. All other metacarpals move appropriately.

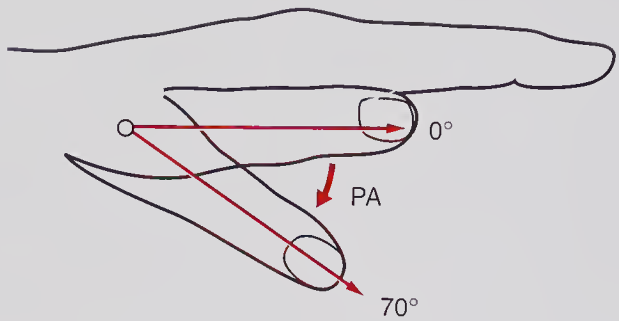


FIGURE 5.40

Abduction of Thumb Thumb may abduct in plane of palm (0 degrees) or at right angle in palmar abduction (PA) to 70 degrees.

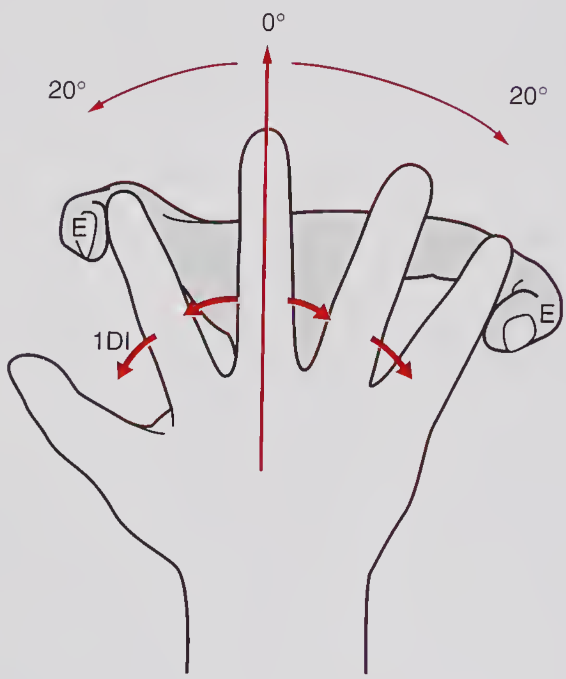


FIGURE 5.41

Abduction-Adduction of Fingers With middle (third) finger as apex, first 2 fingers in abduction are 20 degrees from base, and fourth and fifth fingers are 20 degrees from base. 1DI indicates first digit; E, examiner.

Metacarpophalangeal Joint

The metacarpophalangeal joint is an incongruous joint, with the concavity of the proximal phalanx different from the convexity of the distal end of the metacarpal. With this configuration, the initial flexion of the proximal phalanx from the fully extended digit begins flexion about the axis of the distal portion of the metacarpal in a palmar shear direction. (The distal end of the metacarpal is ovoid rather than fully rounded.) Once flexed to the axis of the rounded palmar aspect of the distal metacarpal, the proximal phalanx flexes about the axis (Figure 5.42).

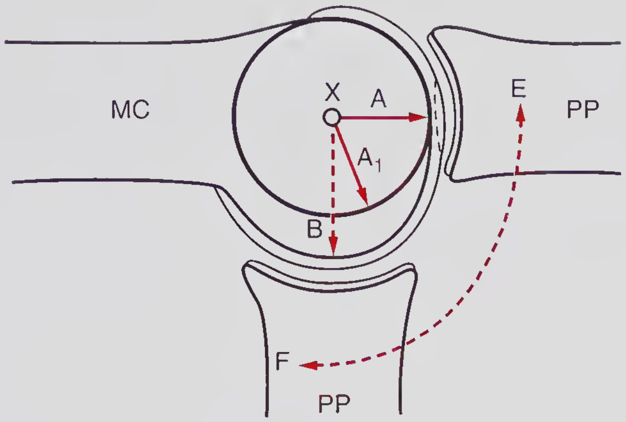


FIGURE 5.42

Incongruous Articulation of Metacarpal-Proximal Phalanx In distance from axis of rotation (X), A would be rotation of proximal phalanx (PP) were it to rotate about rounded phalanx (A_1). But because distal end of metacarpal (MC) is ovoid (B), flexion (F) means a palmar translation initially, before flexion occurs about new axis of rotation. E indicates extension from flexion.

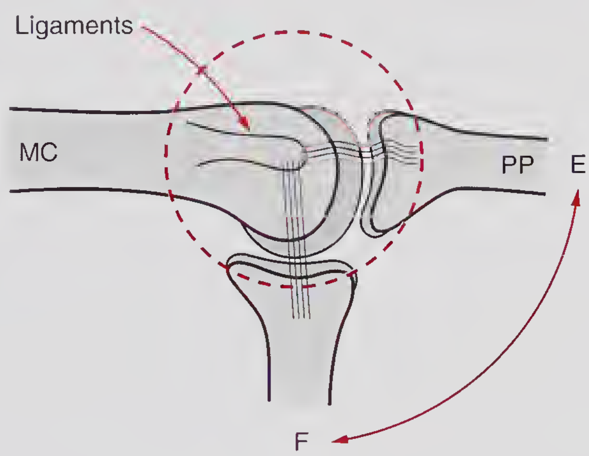


FIGURE 5.43

Collateral Ligaments of Metacarpal-Proximal Phalangeal Joint Due to incongruity of joint, collateral ligaments are slack when finger is extended (E) and taut when flexed (F). MC indicates metacarpal; PP, proximal phalanx.

The collateral ligaments of the metacarpophalangeal joint are slack when the fingers are extended, allowing abduction and adduction (Figure 5.43). However, the ligaments become taut when flexion occurs to 90 degrees, allowing no abduction-adduction in the flexed finger position.

The heads of the metacarpals are flat when viewed from above, adding to the tautness of the collateral ligaments in the flexed finger. The collateral ligaments originate from a small tubercle eccentrically located on the lateral surfaces of the head; in the extended position, these ligaments allow lateral movement. There are no ligaments on the dorsal surface of the metacarpophalangeal joint.

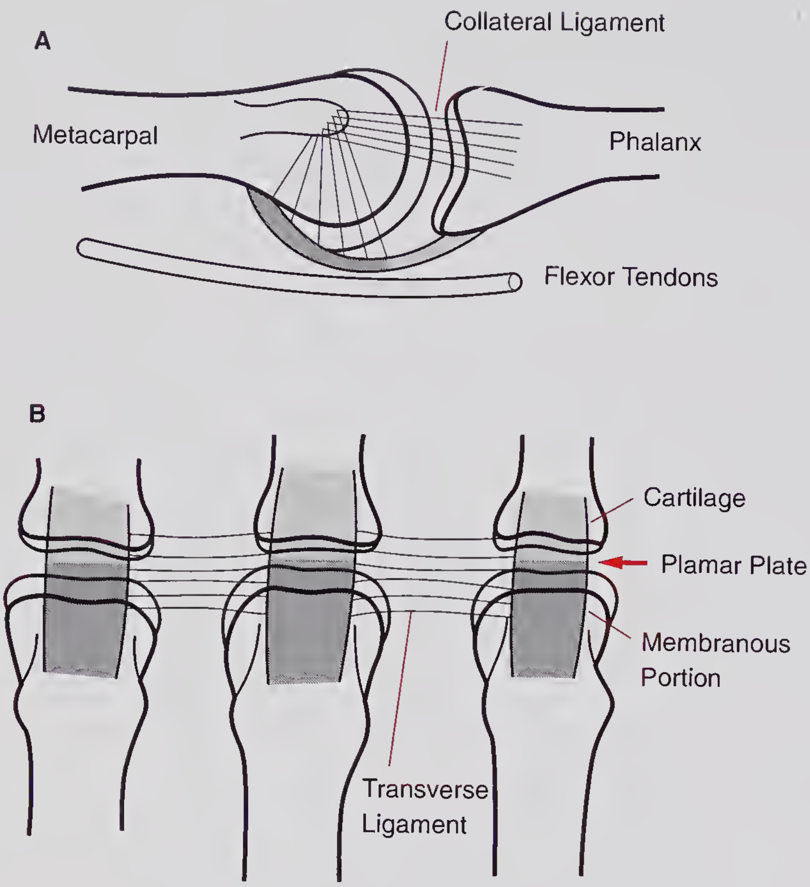


FIGURE 5.44

Palmar Plates Fibrocartilaginous "plate" essentially replaces ligaments on palmar surface of joint. A, Plates are held firmly to metacarpal by fibers of collateral ligament. B, Palmar view shows deep transverse ligament that connects plates and prevents lateral motion of all metacarpals except thumb. Proximal membranous portion is loosely attached to metacarpal.

There are "plates" in the palmar surface of the capsule that limit motion. The distal portion of the plate is cartilaginous and firmly attached to the proximal portion of the phalanx. The proximal portion of the plate is membranous and is loosely attached to the metacarpal. The plates reinforce the joint capsules and are interposed between the joint and the flexor tendons. They are firmly held against the joints by fibers of the collateral ligaments. The plates are connected by deep transverse ligaments, which have an outpouching on the palmar surfaces, termed the *vaginal ligaments of the fingers*, and which enclose the flexor tendons (Figures 5.44, 5.45, 5.46).

Phalanges

There are 14 phalanges in each hand. The thumb has 2 phalanges, and the other 4 fingers have 3. The interphalangeal joints are true hinge joints, allowing flexion and extension. The metacarpal-phalangeal joint permits

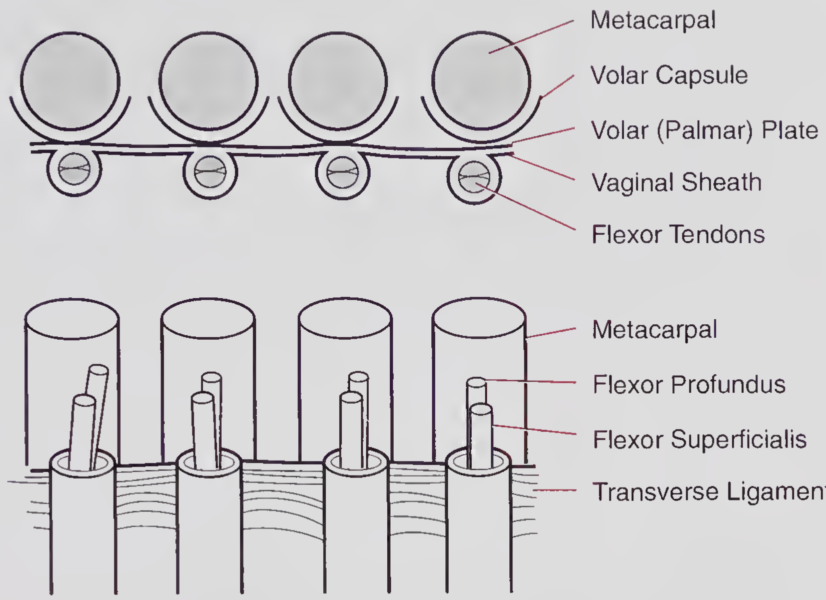


FIGURE 5.45

Transverse Metacarpal Ligament Volar fibrocartilaginous plate reinforces joint capsule. It also forms dorsal portion of vaginal ligament, which forms pouches that encircle flexor tendons as part of flexor gliding mechanism. These pouches form part of lubricating apparatus of flexor tendons and prevent bowing.

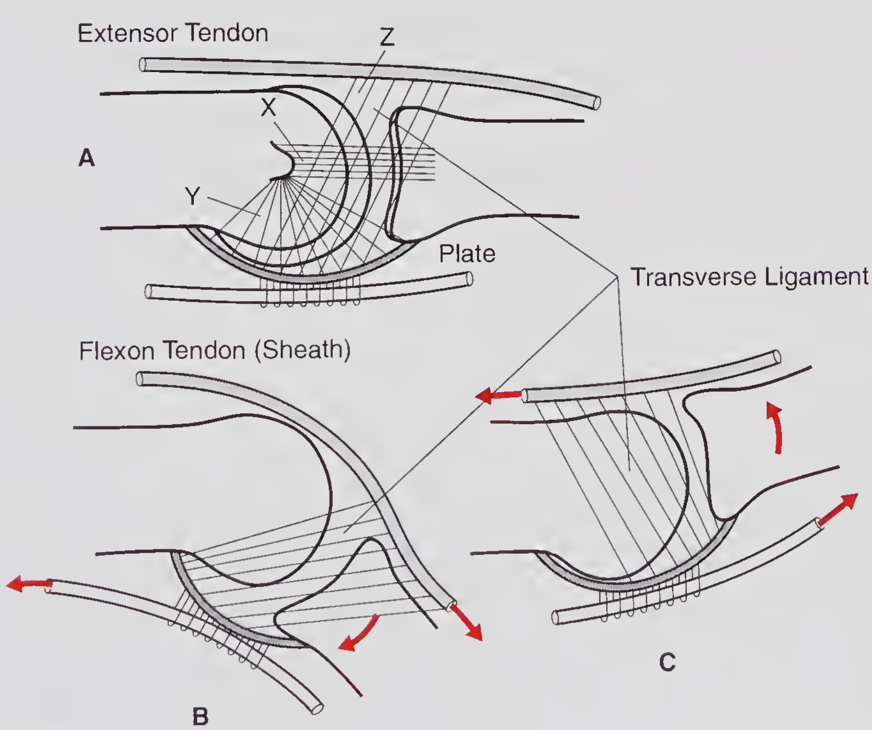


FIGURE 5.46

Metacarpophalangeal Ligaments A, Collateral ligaments (X) make up metacarpophalangeal ligament and metacarpoglenoidal component (Y), which suspends palmar plate and, in turn, flexor tendons (Z). Transverse ligament connects extensor tendon to palmar plate and flexor tendon. B, Finger flexion. C, Finger extension.

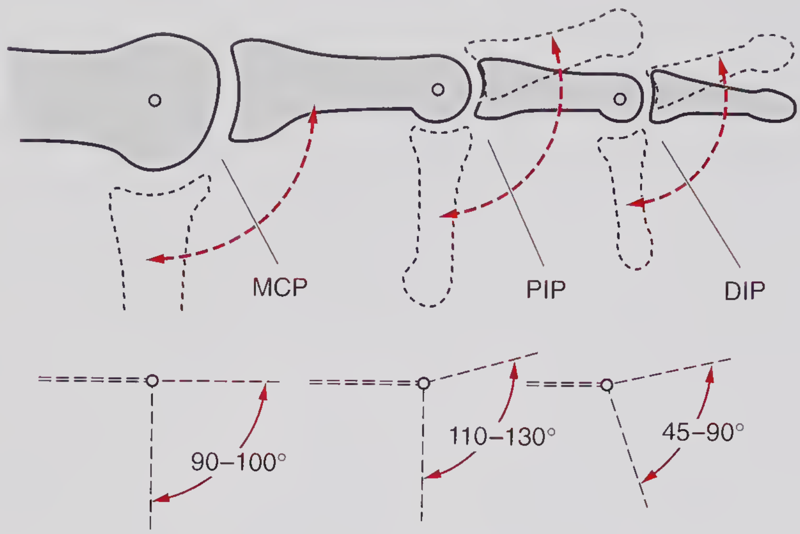


FIGURE 5.47

Range of Motion of Interphalangeal Joints Metacarpal-phalangeal joint (MCP) has a range of 90 to 100 degrees. Proximal interphalangeal joint (PIP) averages 110 to 130 degrees. Distal interphalangeal joint (DIP) averages 45 to 90 degrees.

abduction, adduction, and circumduction. This joint is a ball-and-socket joint. Due to capsular and ligamentous laxity, hyperextension is possible with passive force. The collateral ligaments that are slack in extension and taut in flexion do not exist in the interphalangeal joints (Figure 5.47).

EXTRINSIC MUSCLE-TENDINOUS CONTROL

The extrinsic muscles have been discussed and illustrated (refer to Figures 5.11 and 5.12) and consist of the superficial extensor muscles, deep layer of forearm extensors, and the palmar flexor muscles. The tendons insert on the digits (described as follows).

Flexor Tendons

Each flexor profundus tendon inserts into the base of the distal phalanx (Figure 5.48). It is initially cylindrical but flattens as it passes the divided superficialis tendon, where it flattens from front to back. The flexor superficialis tendon divides at the midpoint of the proximal phalanx (Figure 5.49). Over the proximal middle phalanx articulation, it divides into a medial and a lateral extension, to form a "V." Each extension, in turn, divides into and crosses over to the opposite side. The final division, one fourth of the

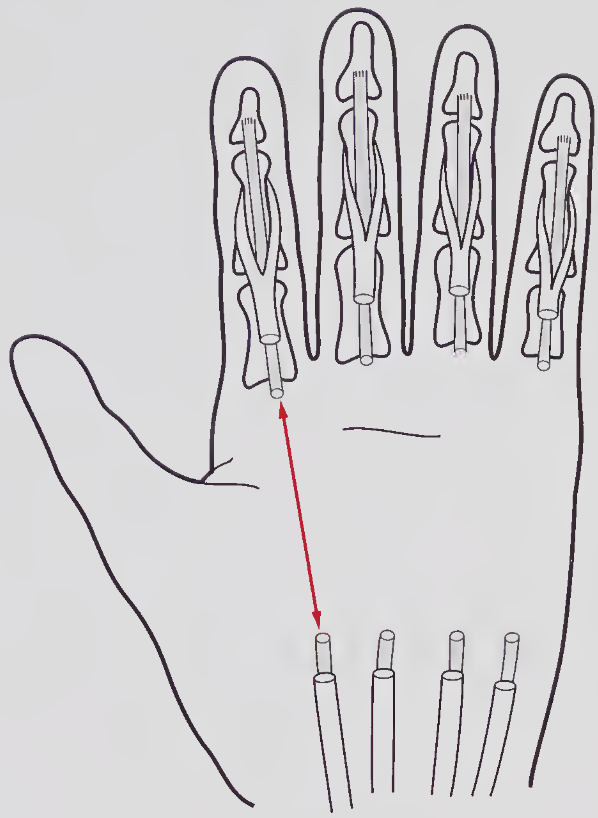


FIGURE 5.48

Insertion of Flexor Tendons At wrist, flexor digitorum superficialis tendons are arranged in 2 layers—2 inner tendons lying deep and 2 outer tendons lying more superficially. In their course, these tendons split, to allow profundus tendons to pass through division and then attach to middle phalanges of 4 medial fingers. Flexor profundus tendons at wrist are in 1 layer and in same sheath as flexor superficialis tendons. They pass between split of superficialis tendons and attach to base of distal phalange.

original tendon and half of the split, passes under the profundus tendon, which has passed through the initial division of the superficialis tendon.

There are sheaths that encircle the tendons, afford lubrication, and protection. These sheaths are compartments (tunnels) related to the palmar fascia. The palmar fascia passes distally from the transverse carpal ligament and divides into 4 bands that pass down to the 4 metacarpals. When the fascia reaches the metacarpal heads, it blends with the deep transverse ligament. Both the profundus and superficialis tendons are enclosed within these compartments (Figures 5.50, 5.51, 5.52).

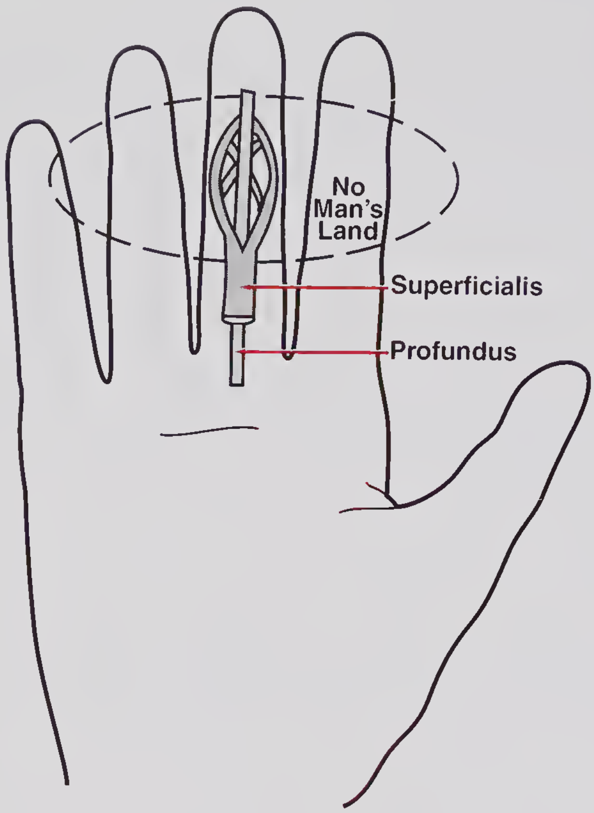


FIGURE 5.49

Digital Flexor Mechanism Profundus tendon inserts into entire breadth of base of distal phalanx, into palmar plate, and then into pulp of finger. Superficialis tendon splits midway past proximal phalanx. Three fourths of fibers continue and attach to lateral crest of middle phalanx. One fourth crosses under tendon of profundus, which has passed through perforation of superficialis tendon.

INTRINSIC MUSCLES

Whereas the extrinsic muscles originate outside the hand, the intrinsic muscles originate in the hand and act on the digits. They comprise the following groups of muscles:

- Thenar, which performs thumb functions.
- Hypothenar, which performs functions of the little (fifth) finger.
- Interosseous and lumbrical muscles, which perform adduction and abduction of the fingers and which combine with the extensor tendons to extend the fingers.

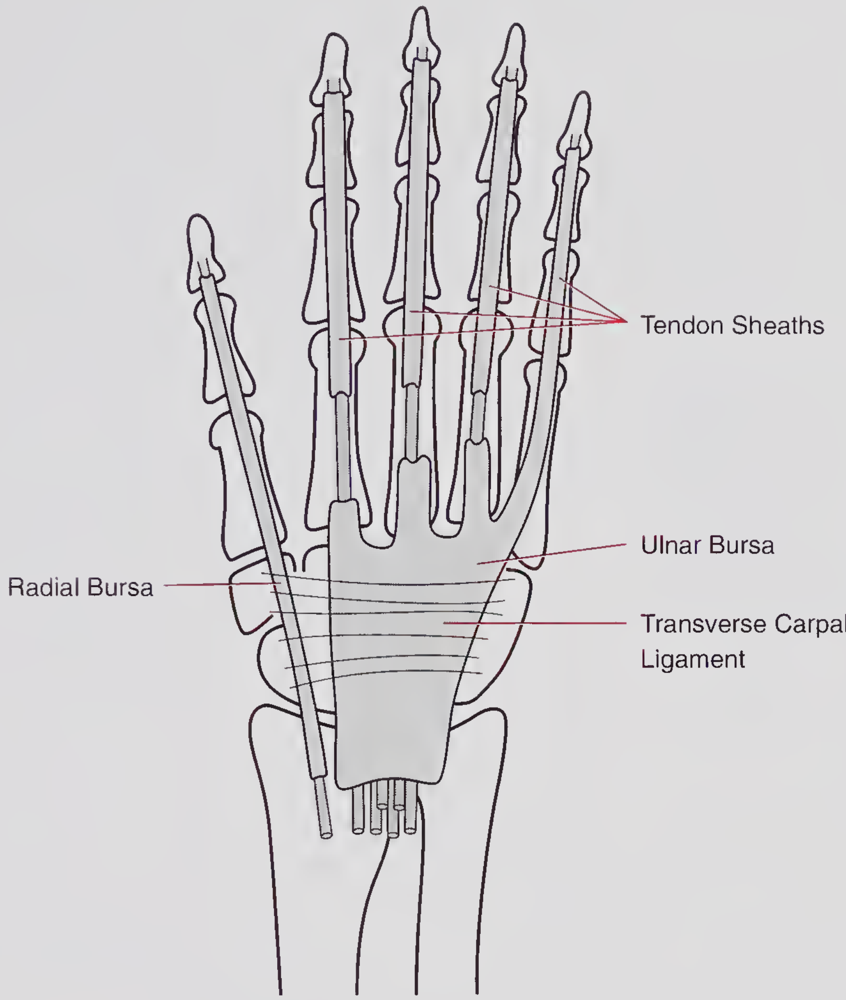


FIGURE 5.50

Tendon Sheaths and Flexor Bursa Tendon sheaths of index, middle, and ring fingers extend from midpalmar crease to insertion of flexor profundus tendon into distal phalanx. Sheath of fifth finger continues from ulnar bursa, which is found in palm under transverse carpal ligament. Ulnar bursa forms 3 compartments—1 superficial to superficialis tendon, 1 between superficialis and profundus tendons, and 1 under profundus tendon. Thumb bursa (radial bursa) extends from under transverse carpal ligament to accompany flexor tendon to its insertion at distal phalanx. In 15% to 20% of persons, fifth tendon sheath does not communicate with ulnar bursa, and occasionally all tendon sheaths connect with bursa.

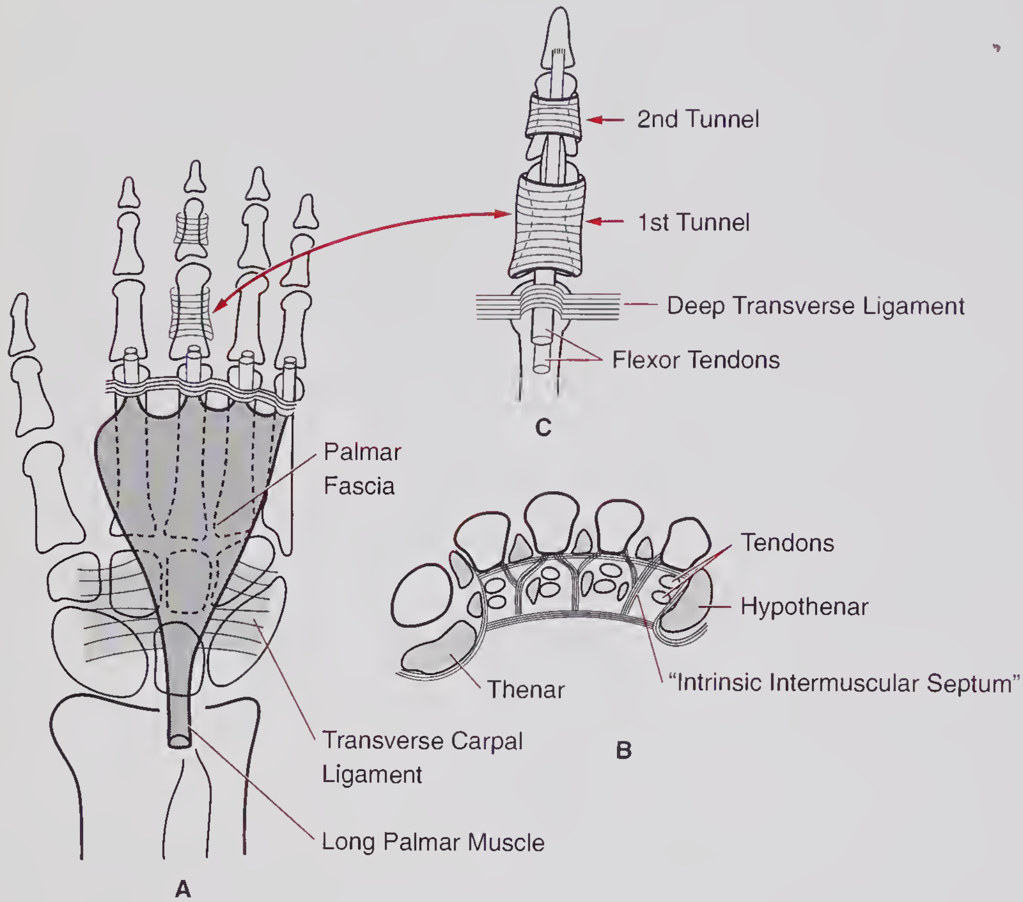


FIGURE 5.51

Palmar Fascia A, Course of palmar fascia is over transverse carpal ligament and fanning out to 4 medial fingers. B, Septa arising from fascia descend down to metacarpals, forming compartments that each contain flexor tendons and intrinsic muscles. C, Fibrous tunnels enclose flexor tendons.

The interosseous consist of 4 dorsal and 3 palmar muscles. The dorsal interosseous are bipenniform muscles that arise from adjacent sides of the opposing metacarpals and converge into lateral bands that attach to the extensor mechanism. The first dorsal interosseous muscle originates from 2 bellies and inserts on the radial side of the first metacarpal, producing adduction of this metacarpal. It inserts on bone, and the radial artery passes between the 2 heads of its origin.

The second and third interosseous muscles insert on the middle finger, and the fourth inserts on the ulnar side of the ring finger. Their function is to abduct the index and ring fingers from the midline. They may move the middle finger in either direction—medial or lateral. In half of the population, they insert on bone and in the rest they insert on the extensor mechanism. The interosseous tendons pass dorsally to the transverse palmar ligament.

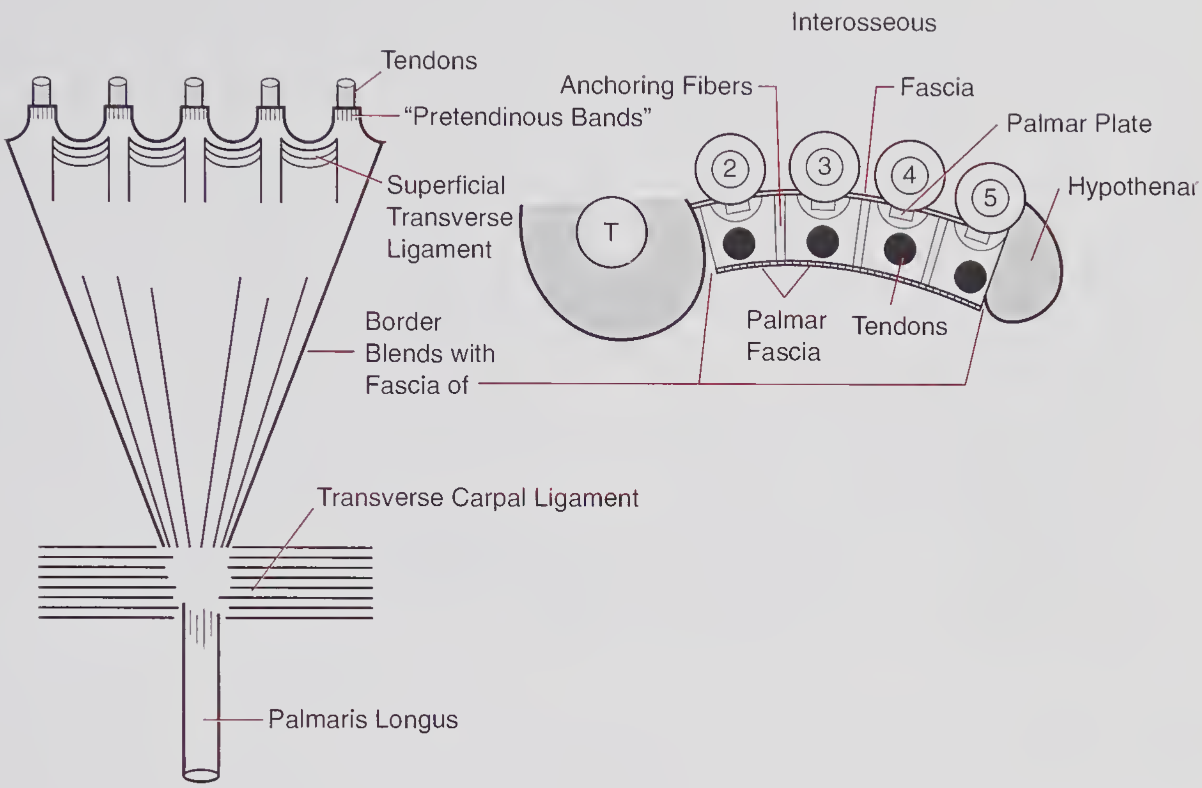


FIGURE 5.52

Triangular Layer of Fascia Triangular layer of fascia has its apex continuous with transverse carpal ligament in this schematic. It fans distally over heads of metacarpals into thickened pre-tendinous bands that overlie flexor tendons and connect with superficial transverse ligament. Fibrous bands proceed dorsally to interosseous fascia between metacarpals, forming compartments for flexor tendons. Deep transverse metacarpal ligament blends with flexor palmar plates, forming fibrous sheaths into tunnels. T indicates thumb.

The 3 palmar interosseous muscles function as adductors of the fingers toward the middle finger. The first palmar interosseous muscle arises from the ulnar side of the second metacarpal and attaches to the extensor mechanism on the same side of the metacarpal. The second interosseous muscle originates from the radial side of the fourth metacarpal, and the third interosseous muscle originates from the fifth (little) finger, to attach to the extensor mechanism on the radial side.

There are usually 4 lumbrical muscles that arise from the radial side of the tendons of the flexor digitorum profundus and pass along the same side of the corresponding finger to attach to the extensor mechanism. Whereas the 7 interosseous muscles pass behind the deep transverse ligament, the lumbrical muscles pass in front of the ligament. Their function is more for precise motion than for strength (Figures 5.53, 5.54, 5.55).

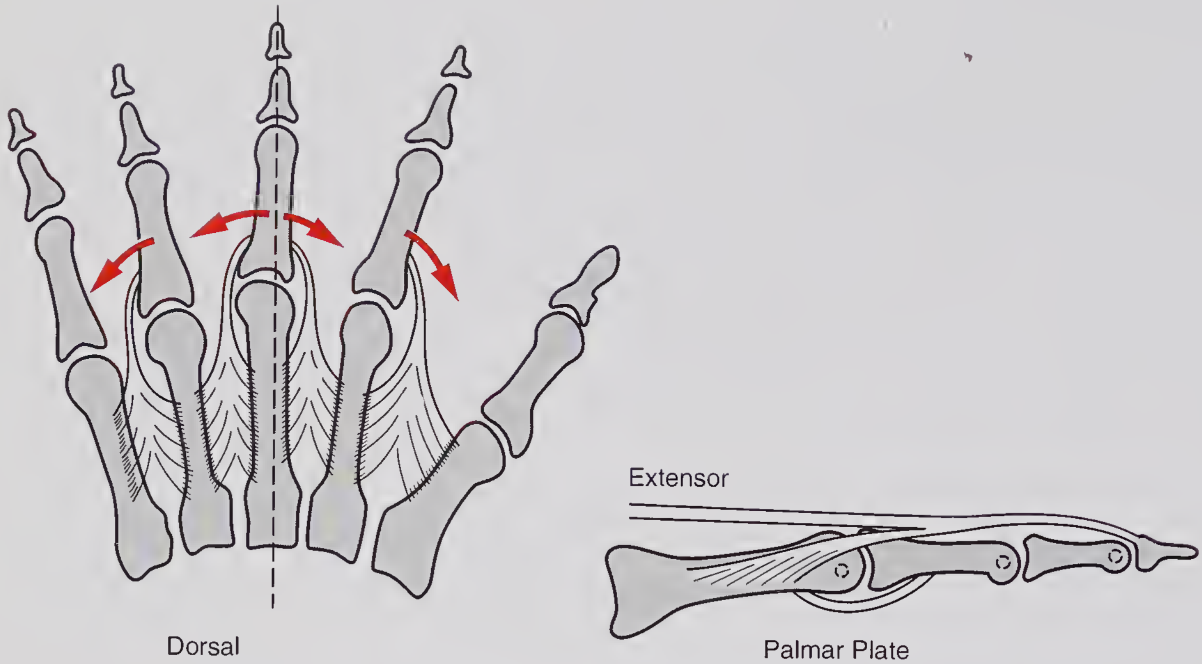


FIGURE 5.53

Dorsal Interosseous Muscles The dorsal interosseous muscles with short abductor muscle of thumb and abductor muscle of little finger spreading fingers. They move digits away from axial line of hand—middle finger. Interosseous muscles arise from double muscle bellies and pass dorsally to transverse palmar ligaments. First dorsal interosseous muscle usually attaches to bone, and others attach to extensor mechanism.

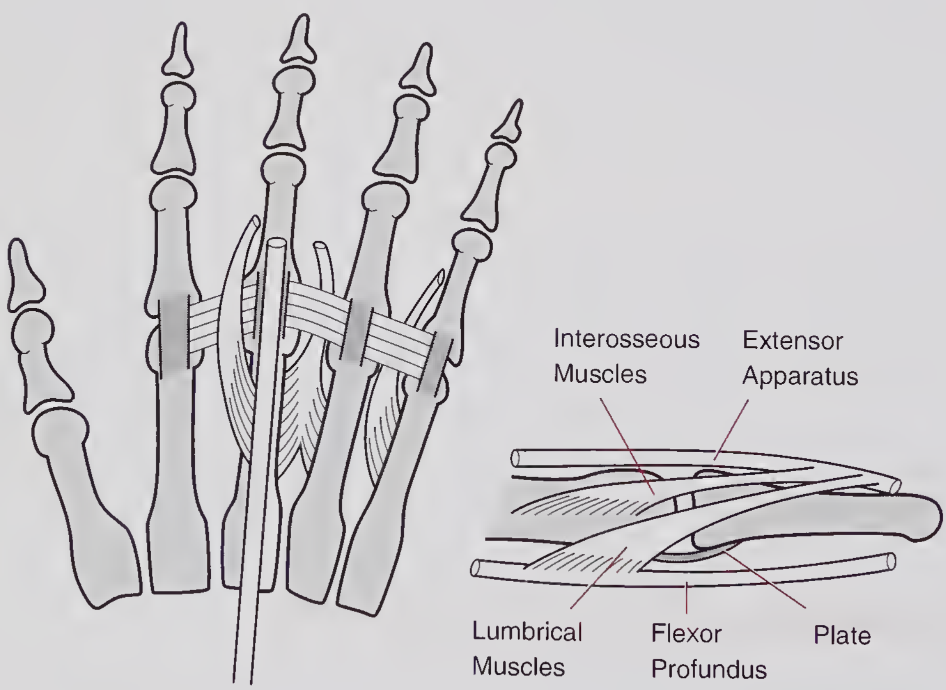


FIGURE 5.54

Relationship of Intrinsic Muscles to Transverse Ligament A, Palmar view of left hand. B, Lumbrical muscles originate from flexor tendons passing dorsally, to unite with interosseous muscles and extensor mechanism.

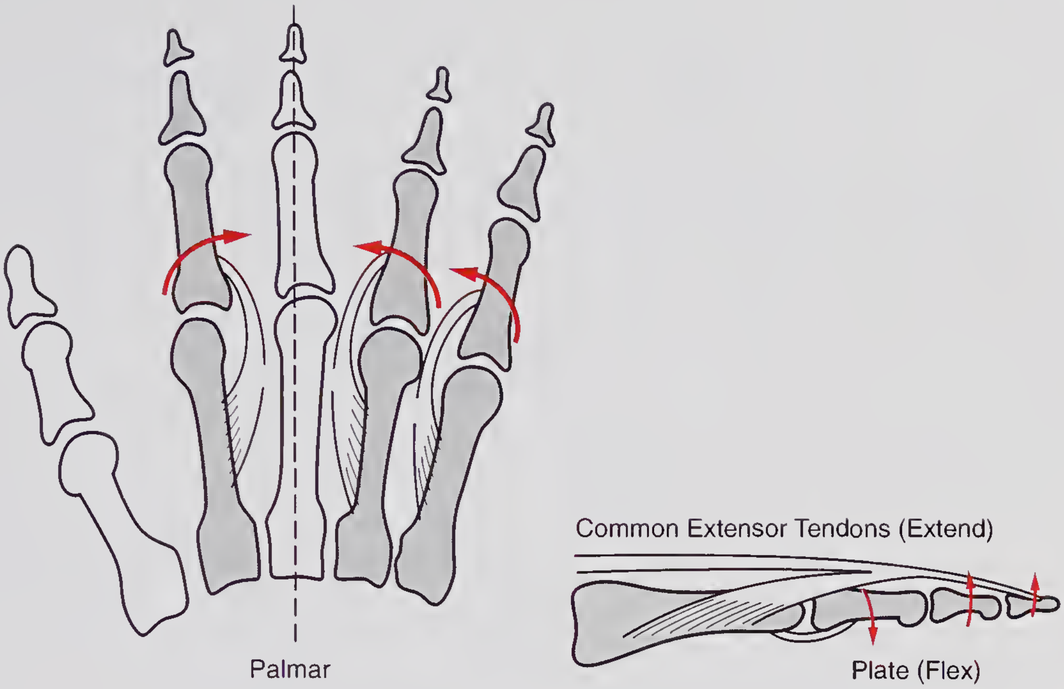


FIGURE 5.55

Palmar Interosseous Muscles Only 3 palmar interosseous muscles arise from second, fourth, and fifth metacarpals. Their tendons pass dorsally, to attach to common extensor tendons. They adduct fingers to which they attach. Thumb has its own adductors.

A "functional" terminology describing the interosseous and lumbrical muscles can be stated as follows:

1. The interosseous muscle could be called the "muscle lying on each side of the fingers," rather than dorsal or palmar.
2. The first dorsal interosseous muscle would become the "flexor-radial deviator and rotator" of the first metacarpal joint.
3. The first dorsal interosseous muscle would become an "extensor of the 2 distal phalanges of the middle finger."
4. The interosseous muscles of the other fingers would "flex and rotate" these fingers.
5. The interosseous muscles of the second, third, and fourth fingers would be "extensors of the distal 2 digits."
6. The lumbrical muscles would be described as "interphalangeal extensors."

EXTENSOR DIGITAL MECHANISMS

The 4 tendons of the extensor digitorum muscles pass over the dorsum of the hand and under the extensor retinaculum at the wrist, where they are enclosed within a synovial sheath (Figure 5.56). From there, they proceed along the dorsum of the phalanges. At the distal end of the proximal phalanx, the extensor tendons split into 2 tendons, which become joined to

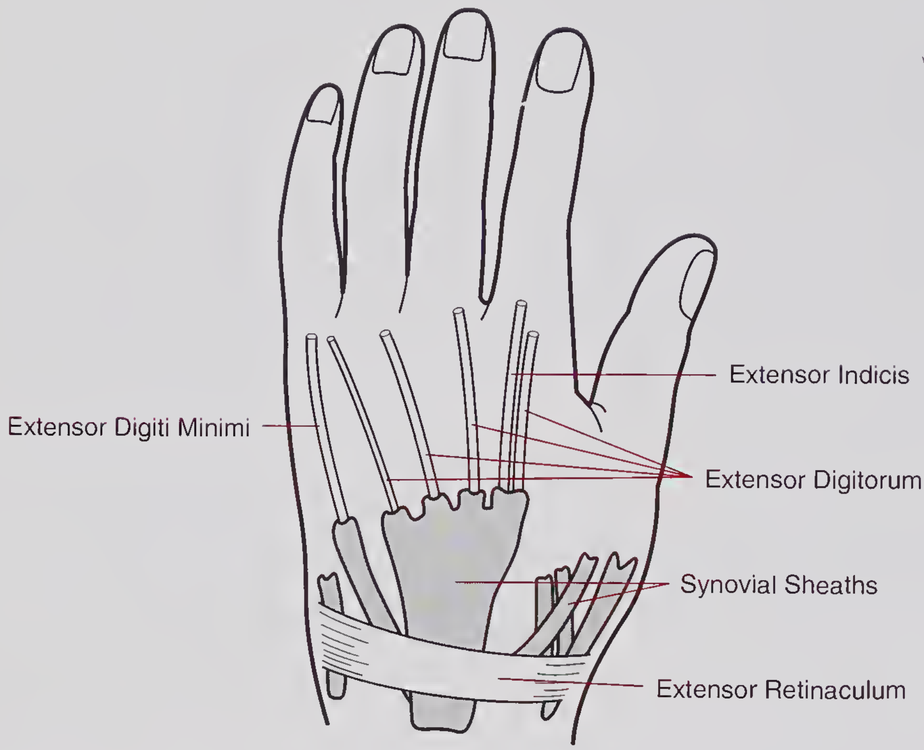


FIGURE 5.56

Extensor Tendon Sheaths There are 6 fibro-osseous tunnels passing under extensor retinaculum. Extensor indicis enters common sheath and proceeds to medial aspect of first finger, there joining extensor tendon. Extensor digiti minimi has its own sheath.

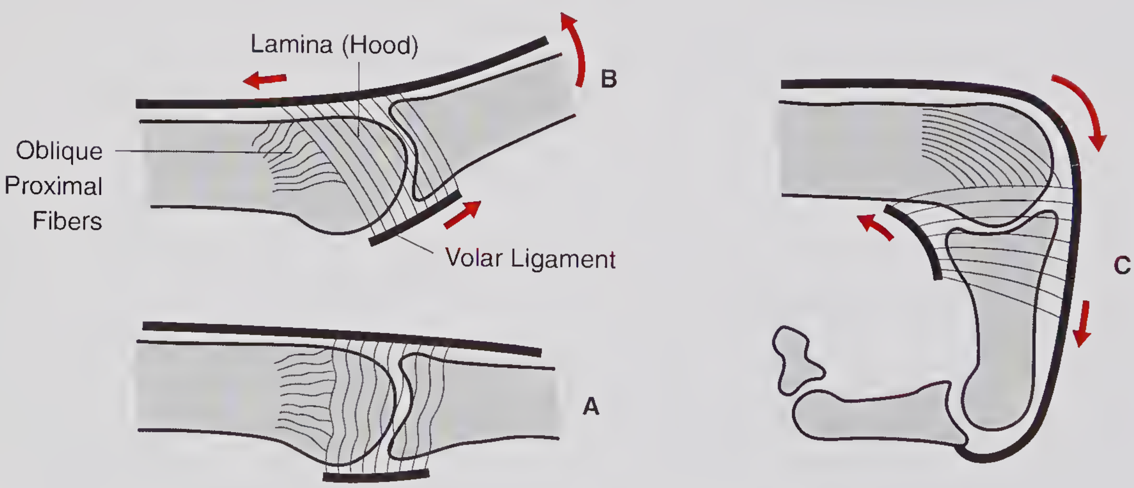


FIGURE 5.57

Extensor Mechanism of Metacarpophalangeal Joint A, Action of transverse lamina (hood) on phalanges with finger in neutral position. Transverse lamina is relaxed permitting digits to be moved laterally by interosseous muscles. In this position, collateral ligaments are also relaxed. B, In hyperextended position, extensor tendon displaces lamina proximally and volar ligament moves distally. Lamina becomes taut, helping to extend proximal phalanx. Oblique proximal fibers that attach from extensor tendon and lamina to metacarpal neck are slack. C, In full flexion, extensor tendon moves distally, causing fibers of lamina and oblique proximal fibers to become taut. Flexor tendon moves volar ligament proximally. Oblique fibers limit extent of motion of extensor tendon.

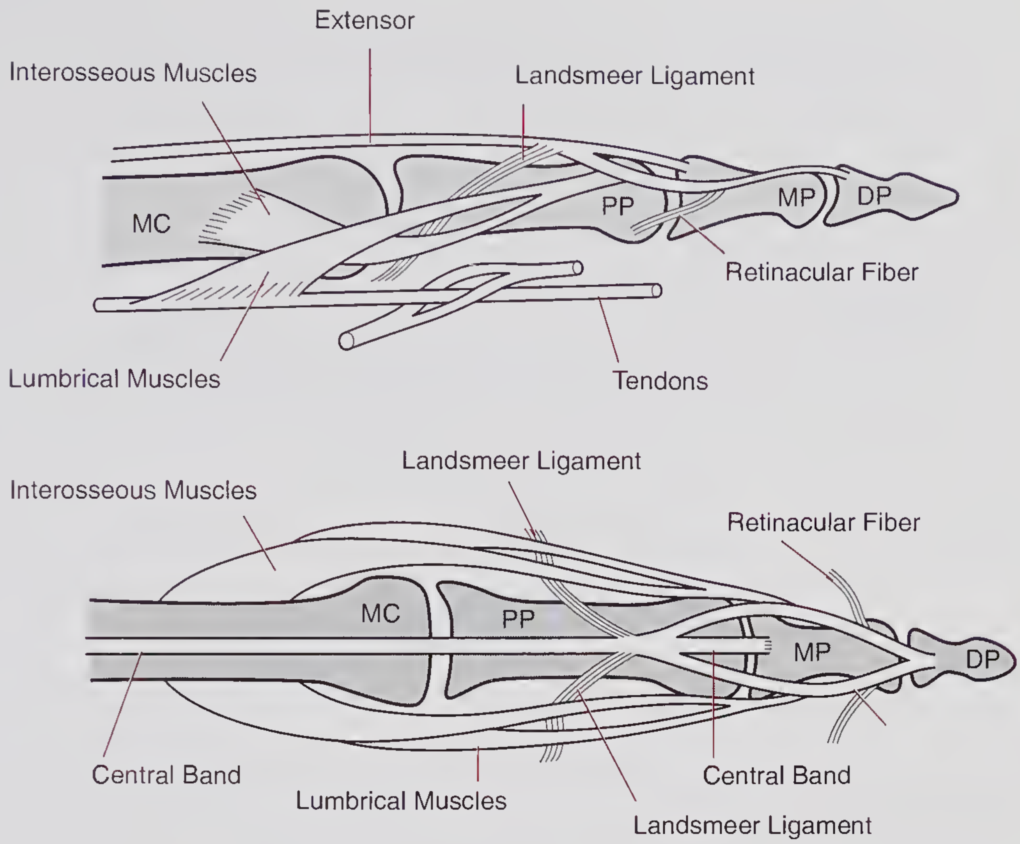


FIGURE 5.58

Extensor Apparatus Extensor digitorum tendon divides into 3 components at distal end of proximal phalanx: central and 2 lateral bands. Central band inserts into proximal end of middle phalanx (MP).Lateral bands pass over lateral aspects of proximal interphalangeal joints (PP) to converge over middle phalanx and insert into proximal portion of distal phalanx (DP). Thin layer of fascia extends laterally from extensor tendon, forming hood that encircles interosseous and lumbrical muscles. MC indicates metacarpal.

the intrinsic muscles—the lumbrical and interosseous—to form the extensor mechanism of the finger.

Each lateral band of the split tendon is joined by half of an interosseous muscle tendon and more distally by a lumbrical tendon. This union is located on the dorsum of the proximal phalanx. These combined tendons ultimately attach to the middle and distal phalanges in conjunction with the lateral bands of the extensor expansion (Figures 5.57, 5.58, 5.59).

Extension of the fingers thus requires combined action of the long extensor tendons and the intrinsic muscles. Extension of the distal interphalangeal joint occurs from the combined action of 3 elements. The central band of the extensor tendon inserts onto the base of the middle phalanx; the 2 lateral bands pass to either side of the proximal interphalangeal joint to fuse distally on the middorsum of the middle phalanx; and, ultimately, the 2 lateral bands insert on the distal phalanx. The middle phalanx extends by virtue of the central slip, whereas the distal phalanx extends by virtue of the 2 combined slips.

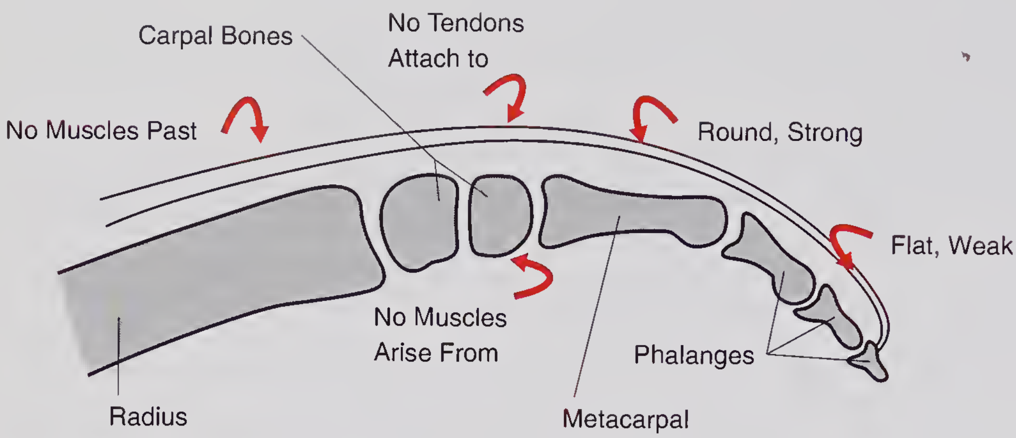


FIGURE 5.59

Dorsal Tendon Course Schematic of dorsal tendons, contours, and ultimate attachment.

RETINACULAR LIGAMENTS

The retinacular system is formed by 2 groups of fibers: dorsal and lateral. Each ligament is formed by a lateral lamina, a longitudinal cord, and oblique fibers. The lateral lamina has transverse and oblique fibers that cover the collateral ligaments of the proximal interphalangeal joint. They are transverse in their proximal part and oblique in their distal portion (Figure 5.60).

The longitudinal cord is thick and composed of few fibers. It runs under the lateral lamina, initially running dorsally to the joint over which it resides. The oblique cutaneous fibers run obliquely from a bony origin on the neck of the proximal phalanx, to attach to the skin over the middle phalanx. The lateral bands of the extensor mechanism migrate dorsally as the proximal interphalangeal joint extends (Figures 5.61, 5.62).

At the distal end of the metacarpal, the extensor tendon flattens to resemble fascia. It wraps around the proximal phalanx, forming an expansion or a "hood," which goes around the phalanx and attaches to the transverse metacarpal ligament (Figure 5.63).

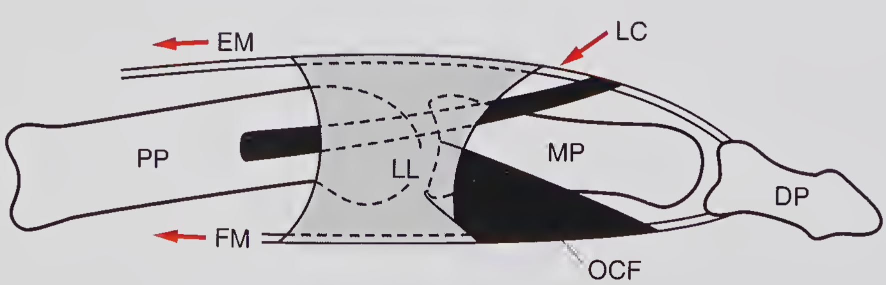


FIGURE 5.60

Retinacular Ligaments Lateral lamina (LL), oblique cutaneous fibers (OCF), and longitudinal cord (LC) connect extensor mechanism (EM) and flexor mechanism (FM) as they control motion of proximal phalanx (PP), middle phalanx (MP), and distal phalanx (DP).

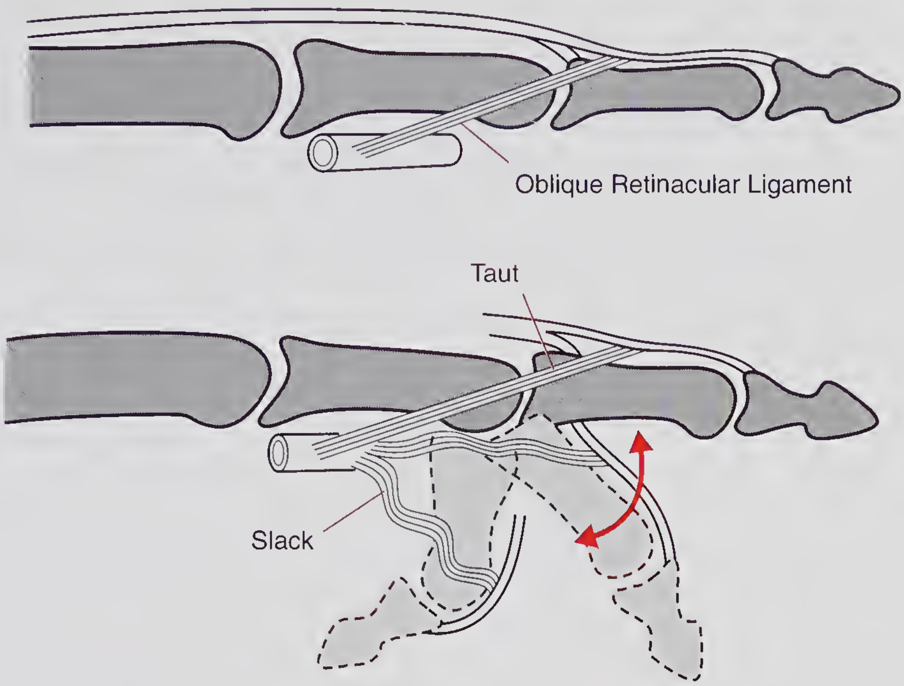


FIGURE 5.61

Oblique Retinacular Ligament Extension of distal joint is aided by tenodesis action of retinacular ligament as proximal joint extends. In flexed position, ligament is slack.

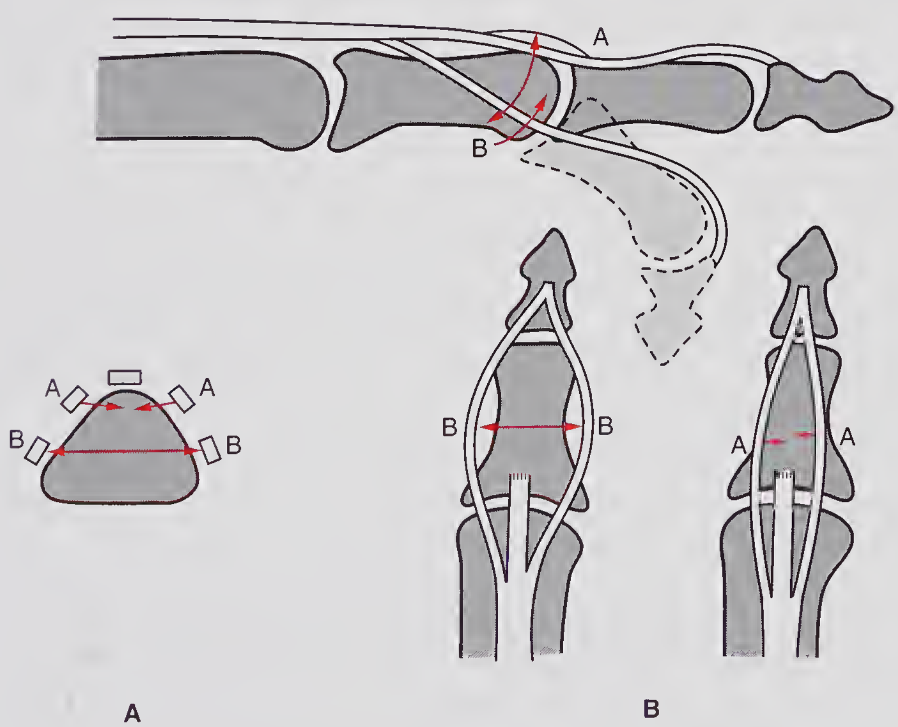


FIGURE 5.62

Dorsal Migration of Extensor Lateral Bands With full extension due to shape of phalanx, bands become taut on dorsum of fingers. A, Relationship A–A is where bands have migrated dorsally in finger extension. B, In flexion, bands migrate ventrally: B–B.

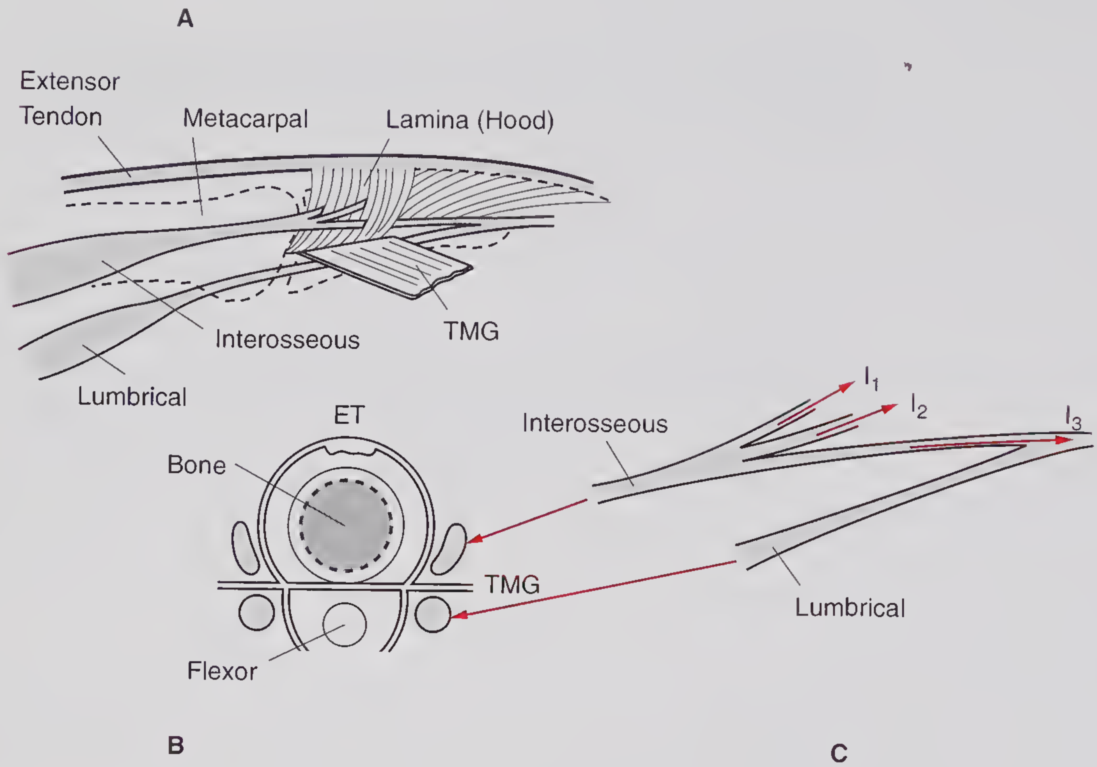


FIGURE 5.63

Extensor Expansion: "Hood" A, As extensor tendon passes end of metacarpal, it expands into a flattened tendon resembling fascia, which wraps around proximal phalanx, forming "hood." Interosseous muscle tendon divides into 3 slips: I_1, I_2, and I_3. I_1 inserts into bone, which allows lateral finger motion: adduction and abduction. I_2 inserts into lamina stabilizing extensor tendon. I_3 proceeds to unite with lumbrical muscle tendon and to merge with lateral bands of extensor expansion. B, Cross-section showing 2 intrinsic muscles (interosseous and lumbrical), transverse metacarpal ligament (TMG), extensor tendon (ET), and palmar longitudinal septum encircling flexor tendons. C, View of distribution of interosseous and lumbrical tendons shown in A.

In forceful gripping, which is primarily a function of the extrinsic flexor muscles, there is also simultaneous activity of the extensors; this is thought to prevent palmar subluxation of the metacarpophalangeal joints during forceful gripping (Figures 5.64, 5.65).

In forceful gripping, there also is a simultaneous contraction noted in the extensor mechanism, which is probably intended to prevent subluxation of the digits or flexor tendons (Figure 5.66).

INTRINSIC MUSCLES OF THE THENAR AND HYPOTHENAR GROUPS

The thenar muscles move the thumb. These muscles include the following: abductor pollicis brevis, which abducts the thumb to the palm of the hand; flexor pollicis brevis, which flexes the thumb; opponens pollicis, which flexes the proximal thumb joint; and abductor pollicis, which abducts the thumb against the plane of the hand.

The hypothenar muscles include the musculus abductor digiti minimi, which abducts the little finger against the plane of the palm; flexor digiti

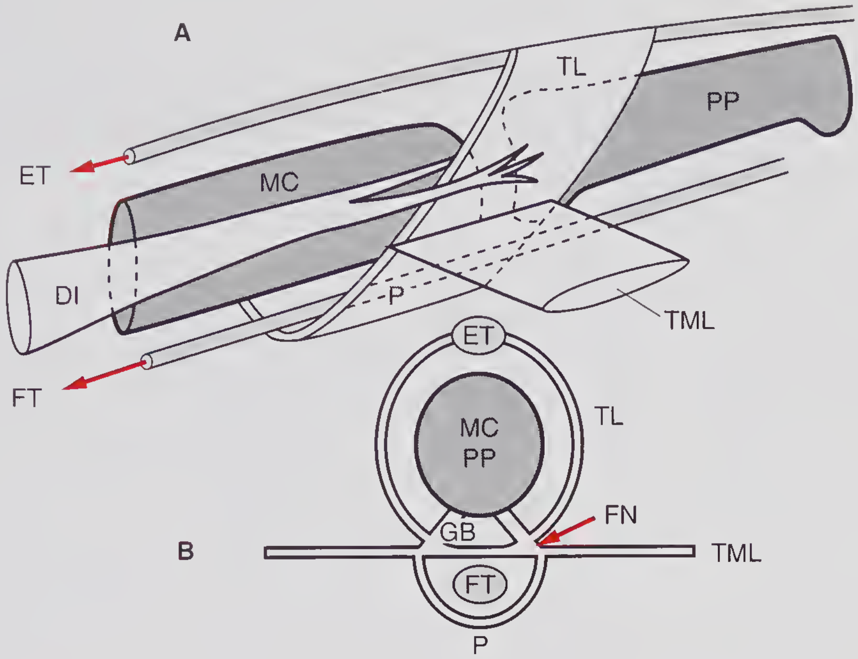


FIGURE 5.64

Complex Flexor Mechanism of Metacarpal Joint A, Metacarpal (MC)-phalangeal joint (PP) flexes in intricate manner, with forces of all involved tissues acting via "force nucleus" (FN). Flexor tendon (FT) moves proximately in pulley (P), which slings from transverse lamina (TL; also called *Landsmeer ligament*). Dorsal interosseous muscle (DI), besides being abductor of fingers, is "force nucleus" during forceful finger flexion. B, "Force nucleus" tissues include glenoid bundle (GB), also called *collateral ligaments*. ET indicates extensor tendon; TML, transverse metacarpal ligament.

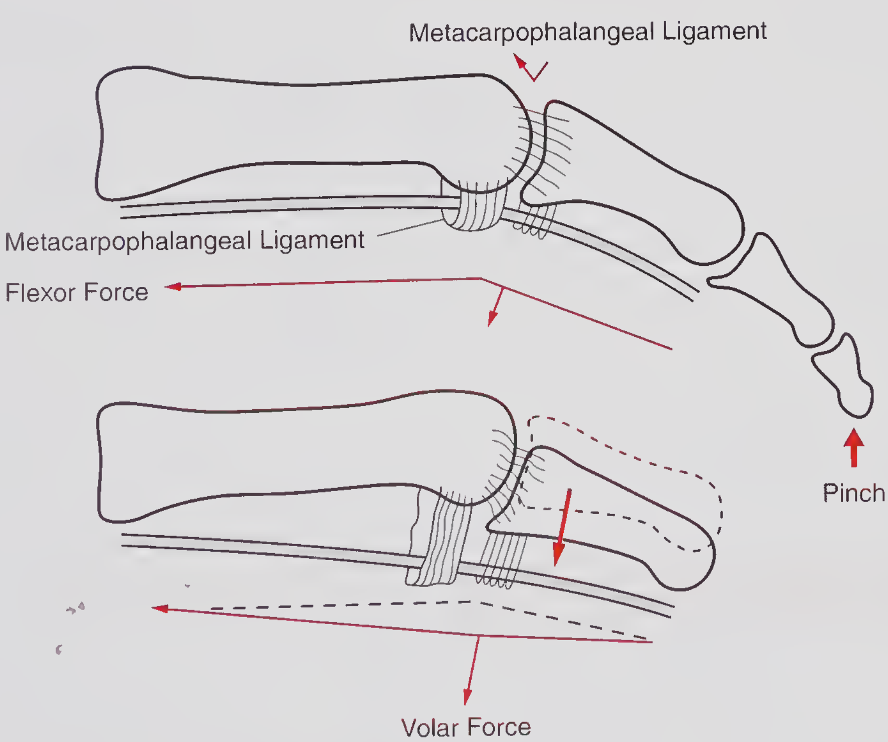


FIGURE 5.65

Pulley System of Metacarpophalangeal Joint During forceful pinching or gripping, there are normal fulcrums of flexor tendons. In any collagen disease, these fulcrums are weakened and result in low palmar subluxation.

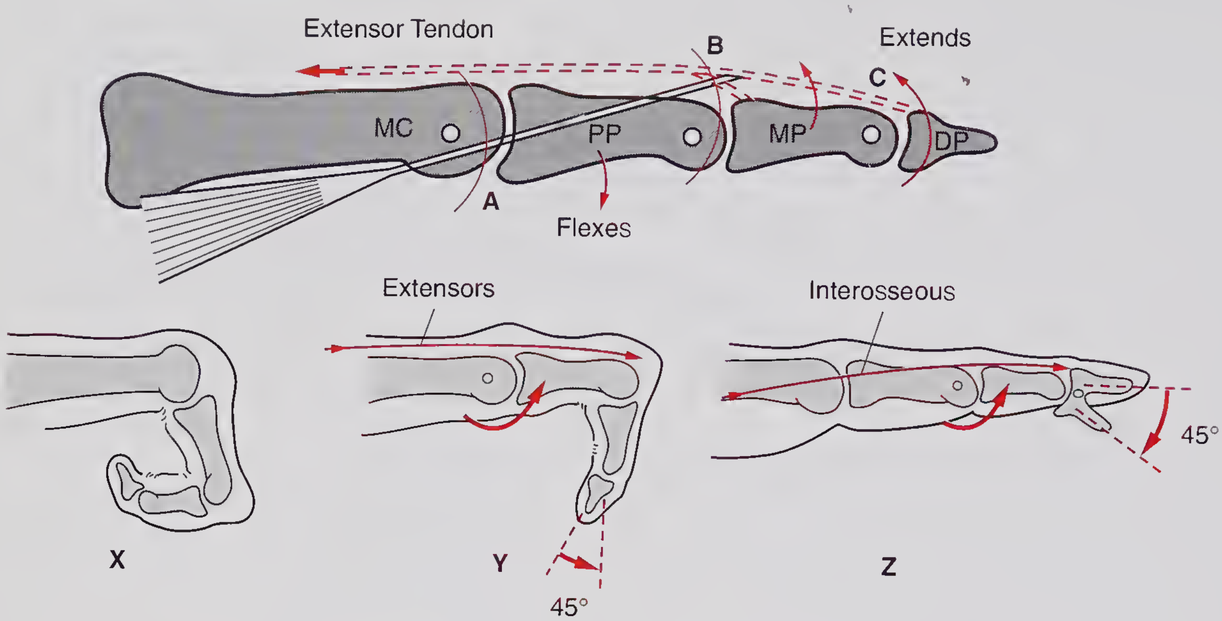


FIGURE 5.66

Action of Long Extensors and Intrinsics A (top left), Intrinsic (interosseous and lumbrical) muscle tendons lie on palmar side of metacarpophalangeal joint and thus flex joint. B (top center), They pass to dorsum of fulcrum of proximal interphalangeal joint and extend this joint. C (top right), Intrinsic muscles attach to extensors, which in turn attach to distal phalanx (DP) extending that joint (distal interphalangeal). Interosseous and lumbrical muscle tendons cannot extend interphalangeal joint (B and C) unless metacarpophalangeal joint (A) is stabilized by extensor, which extends distal phalanx 45 degrees by means of ligamentous action. Z depicts extension of proximal joint, which permits flexion of interphalangeal joint 45 degrees, indicating laxity of Landsmeer ligament. MC indicates metacarpal; PP, proximal phalanx.

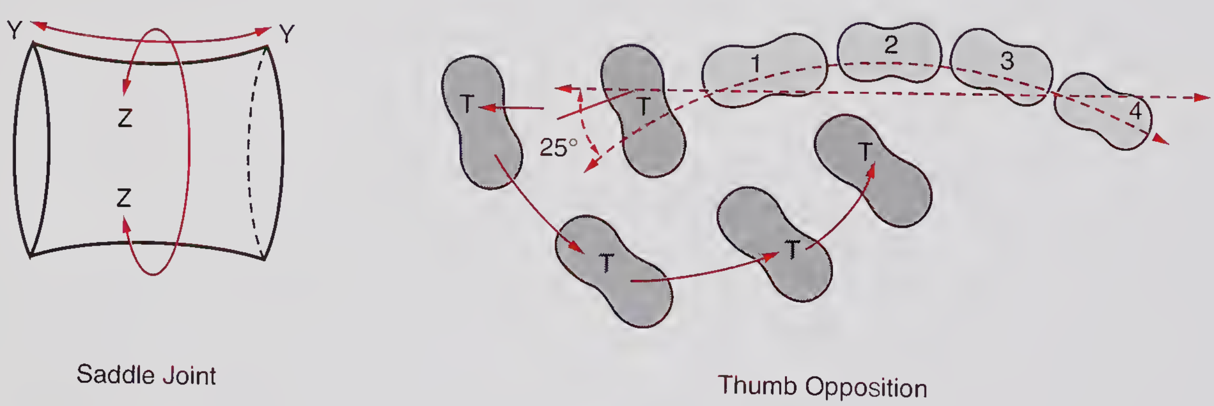


FIGURE 5.67

Thumb-Metacarpal Joint Trapezium-first metacarpal joint (thumb) is saddle joint (S) in which 2 planes of motion that are tangential to each other are possible. Plane of resting thumb (T) is 25 degrees to plane of other metacarpals. Opposition of thumb is combination of consecutive motions: (1) extension in plane of palm, (2) into abduction into palm, (3) flexion of metacarpophalangeal joint, and (4) simultaneous adduction to opposing finger.

minimi, which flexes the proximal phalanx of the little finger; opponens digiti minimi, which opposes the little fingertip against the tip of the thumb; and palmaris brevis (Figures 5.67, 5.68, 5.69, 5.70).

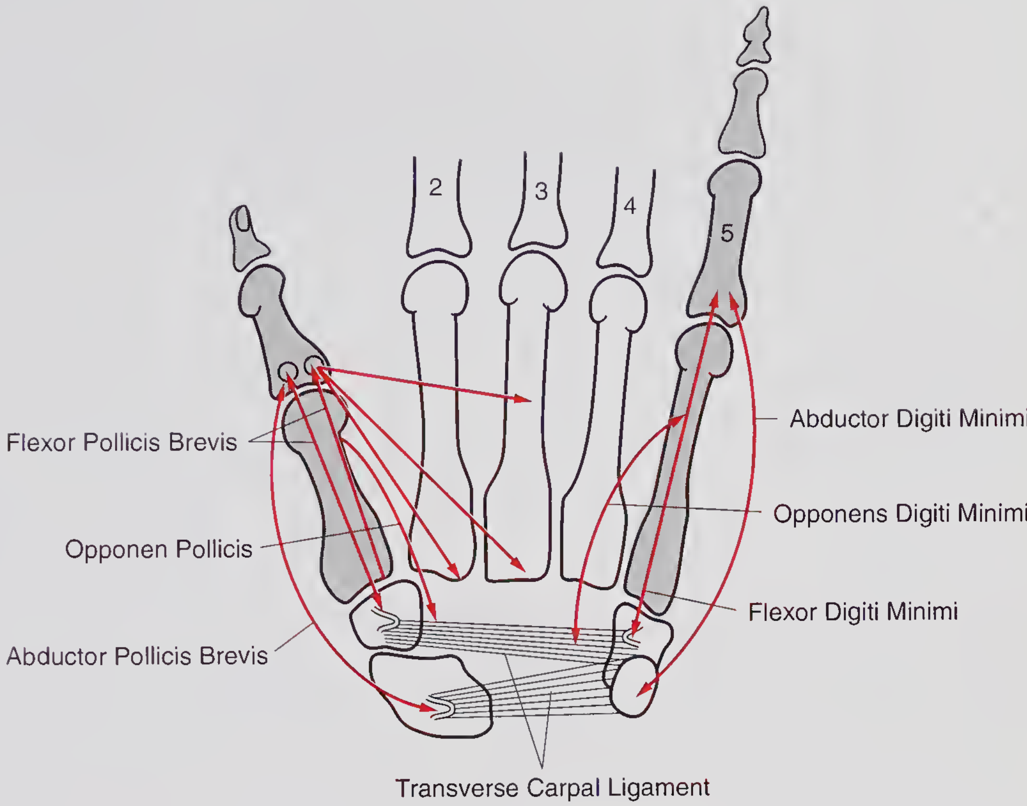


FIGURE 5.68

Muscles of Thenar and Hypothenar Regions Muscles moving thumb and little finger. Only intrinsic muscles are shown in this schematic.

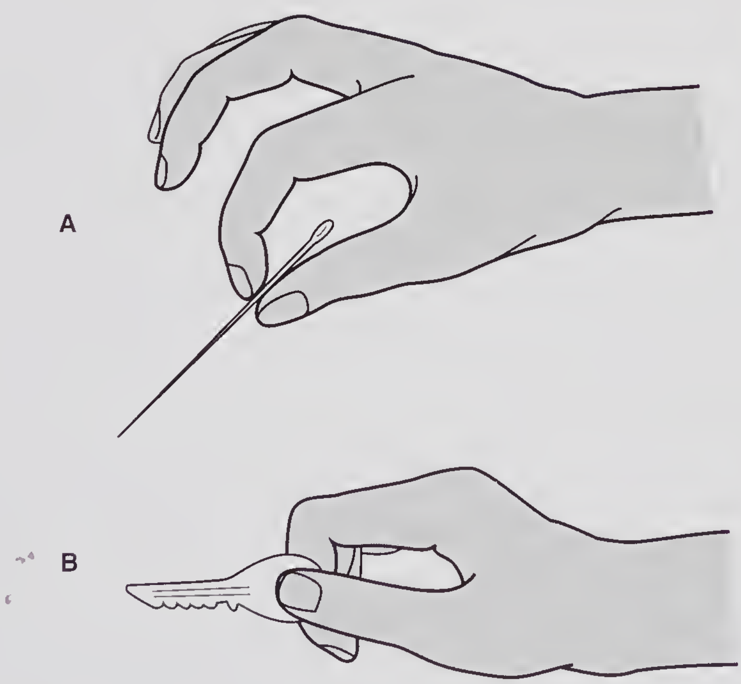


FIGURE 5.69

Pinch Motion of Thumb A, Pinch between tips of thumb and first finger. B, Pinch between tip of thumb and side of first finger.

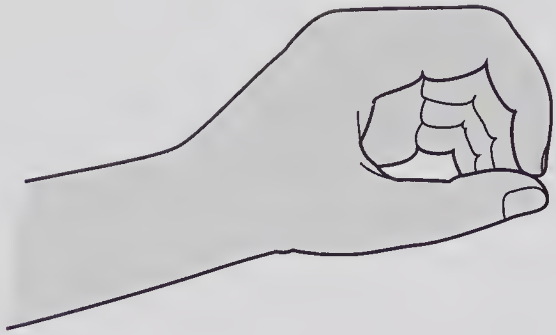


FIGURE 5.70

Opponens Motion of Thumb In motion of musculus opponens digiti minimi, wrist and fingers are flexed, thumb is abducted, and index and middle fingers are opposed to thumb.

NERVE CONTROL OF THE HAND

The nerves that serve the hand originate from the brachial plexus, which divides into peripheral nerves: musculocutaneous, axillary, radial, and median and ulnar, which subserve the hand.

The Median Nerve

The median nerve originates from roots C6, C7, C8, and T1. The muscles it innervates include:

1. Pronator teres (C6, C7), which pronates the forearm.
2. Flexor carpi radialis (C6, C7, C8), which flexes the wrist in a radial direction.
3. Palmaris longus (C7, C8, T1), which flexes the wrist.
4. Flexor digitorum superficialis (C7, C8, T1), which flexes the proximal interphalangeal joints.
5. Flexor pollicis longus (C8, T1), which flexes the digital digit of the thumb.
6. Flexor digitorum profundus (C8, T1), which flexes the distal phalanx of the index (second) and middle (third) phalanx of the first digit.
7. Pronator quadratus (C7, C8, T1), which pronates the forearm.
8. Abductor pollicis brevis (C8, T1), which elevates the thumb at a right angle to the palm.
9. Flexor pollicis brevis (C8, T1), which flexes the metacarpal joint of the thumb.
10. Opponens pollicis (C8, Tl), which opposes the tip of the thumb to the tip of the little or first finger.

The dermatomic (sensory) component of the medial nerve is the palmar aspect of the thumb and first 2 fingers, and the medial aspect of the third finger.

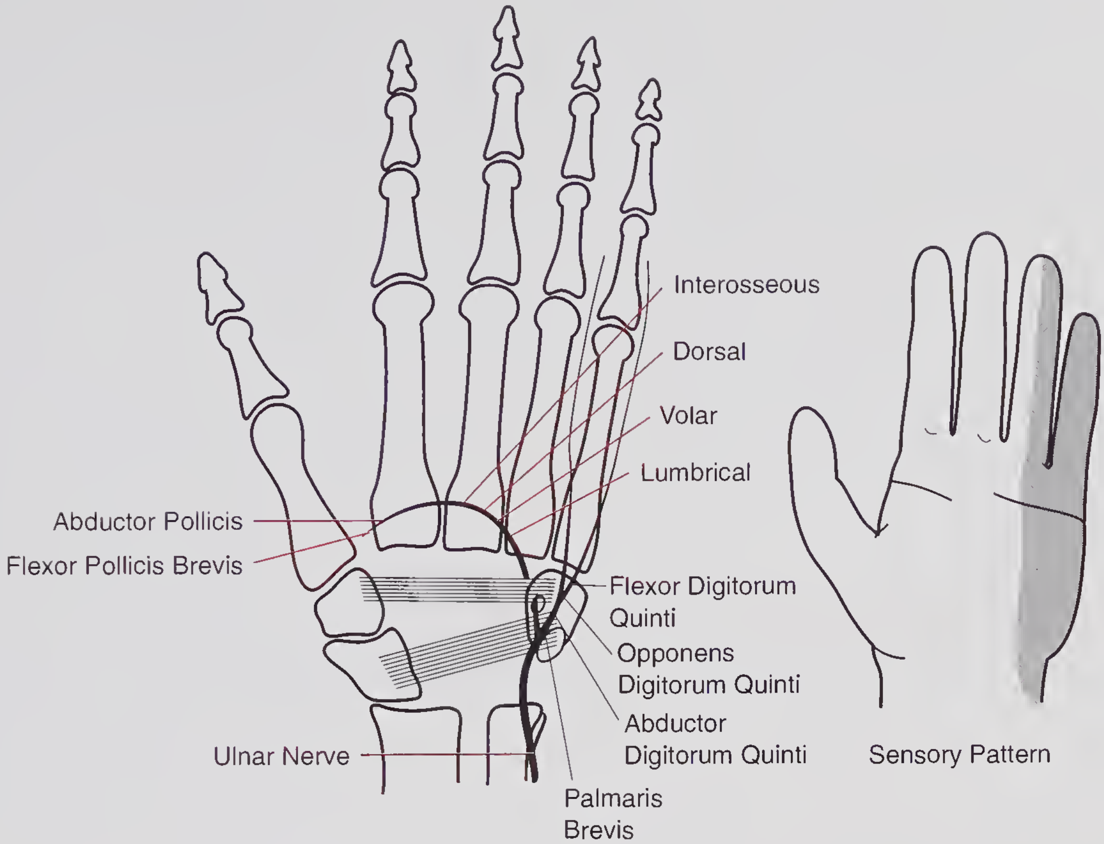


FIGURE 5.71
Ulnar Nerve Muscles and sensory innervation of ulnar nerve.

The Ulnar Nerve

The ulnar nerve is derived from 2 cervical nerve roots, C8 and T1. It supplies the following muscles:

1. Flexor carpi ulnaris (C8,T1), which flexes the wrist in an ulnar direction and also flexes the wrist when it abducts the little finger.
2. Flexor digitorum profundus (C8,T1), which flexes the distal digit of the little finger and often the distal digit of the ring finger.
3. Abductor digiti minimi, which abducts the little finger in the plane of the palm.
4. Opponens digiti minimi, which opposes the little finger toward the thumb.
5. Adductor pollicis, which adduct the thumb in the plane of the palm.
6. Palmar interossei, which adducts the fingers toward the midline.

The sensory (dermatomic) area supplied by the ulnar nerve is the ulnar side of the last 2 fingers—the ulnar surface of the ring and the entire little finger (Figure 5.71).

The Radial Nerve

The radial nerve arises from roots C5, C6, C7, C8, and Tl. In the upper forearm, it divides into 2 branches: a superficial sensory branch and the posterior interosseous nerve, which supplies the following muscles:

1. Supinator (C5, C6), which supinates the forearm.
2. Anconeus.
3. Extensor digitorum (C7, C8), which extends all digits of the fingers other than the thumb.
4. Extensor digiti minimi (C7, C8).
5. Extensor carpi radialis and ulnaris (C7, C8), which extend the wrist in ulnar and radial directions.
6. Abductor pollicis longus (C7, C8), which abducts the thumb in the plane of the palm.
7. Extensor pollicis longus and brevis (C7, C8), which abduct and extend the base of the thumb.

The sensory (dermatomic) distribution of the radial nerve is the dorsum of the hand (Figure 5.72).

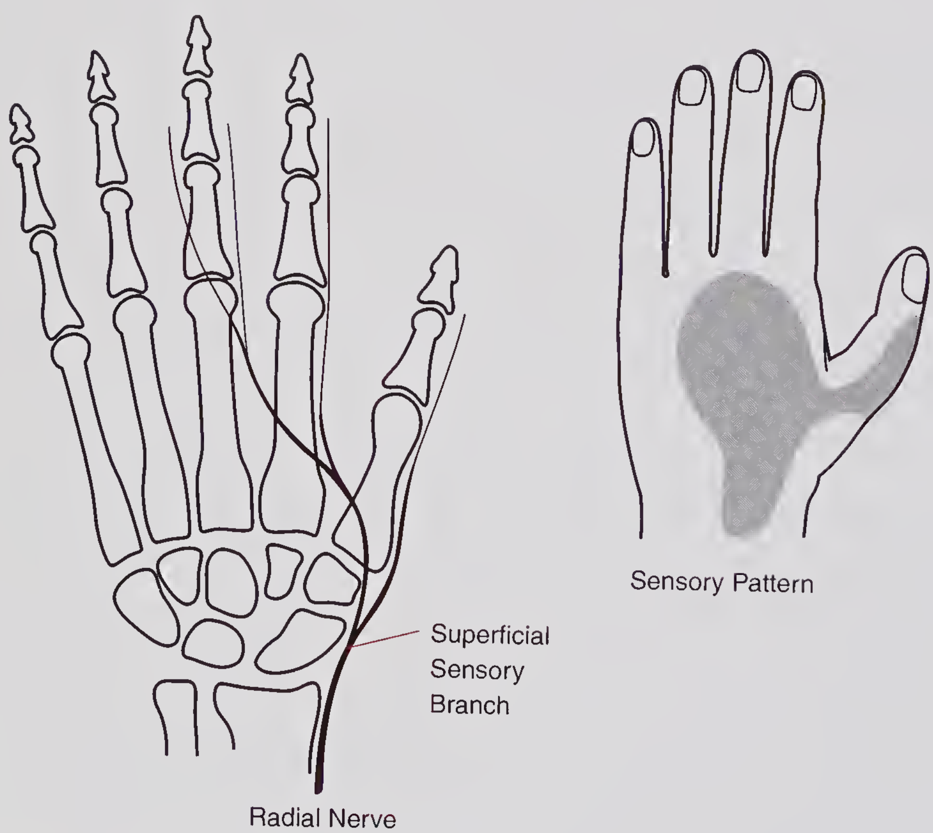


FIGURE 5.72

Radial Nerve Motor and sensory distribution of radial nerve.

FUNCTIONAL ANATOMY OF FREQUENT PAINFUL SYNDROMES OF THE HAND

Of the numerous painful syndromes of the hand, the most frequent involve the base of the thumb. The thumb is a multidirectional joint allowing circumduction as well as flexion, extension, adduction, and abduction (Figures 5.73, 5.74, 5.75).

Another frequent and disabling condition of the fingers (in flexion and reextension) is the snapping tendon. When there is nodularity within the flexor tendon as the nodules passes under and past the annular ligament, it "snaps" and occasionally remains "locked" in its new position. When nodularity occurs in the extensor of the thumb pain, tenderness and locking occurs in the "snuffbox" at the base of the thumb. (Refer to Figure 5.34.)

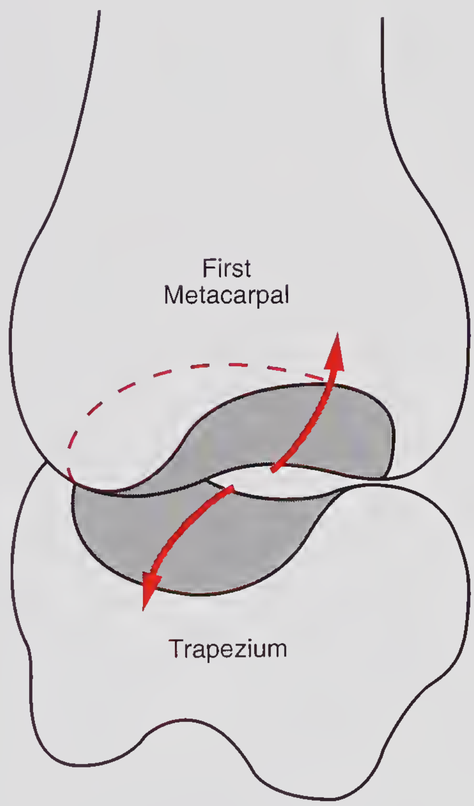


FIGURE 5.73

Metacarpal-Trapezium Joint of Thumb Joint between trapezium and first metacarpal bones allows motion of thumb in all directions.

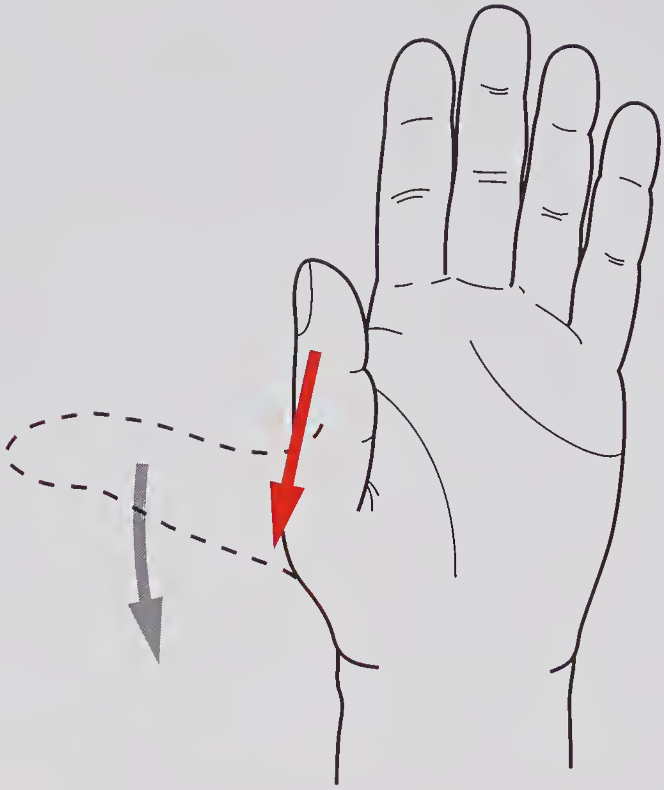


FIGURE 5.74

Abduction of Thumb Abduction is a combination of flexion into the palm and internal rotation.

FIGURE 5.75

Opposition of Thumb To oppose thumb joint to any other fingers, thumb must adduct and internally rotate.

chapter 6

Functional Anatomy of the Knee

The knee is a complex articulation composed of 2 different structural and functional joints that collaborate in their intended function: the femoral-tibial joint and the patellar-femoral joint.

FEMORAL-TIBIAL ARTICULATION

The femoral-tibial articulation of the knee is structurally unstable in its static function except for ligamentous support. In its static and kinetic function, it portrays all the aspects of incongruity (discussed in Chapter 4).

The femoral-tibial joint is formed by the distal end of the femur and the proximal surfaces of the tibia. The distal end of the femur is 2 convex surfaces of condyles separated by a deep U-shaped notch termed the *intercondylar fossa* (Figures 6.1, 6.2).

The femoral-tibial joint is an unstable joint by virtue of its incongruous surfaces. The convexity of the femoral condyles and the curvature of the tibial concavities are asymmetrical and thus not stable. Symmetry and therefore congruity are physiologically restored by bilateral menisci that, with their surfaces, approach congruity, and weight distribution is equalized (Figures 6.3, 6.4). A slight incongruity is needed for appropriate joint lubrication (Figure 6.5).

Menisci

Menisci are curved, wedge-shaped fibrocartilaginous structures located at the periphery of the femoral-tibial joint. They are connected to each other and to the joint capsule. The medial meniscus is approximately 10 mm wide, with its posterior horn wider than its medial portion. The medial meniscus has a wider curvature than does the lateral meniscus. Its anterior horn connects to the anterior ridge of the tibia and to the ventral intercondylar spine by fibrous ligamentous bands. By way of the transverse ligament, it connects to the anterior horn of the lateral meniscus. It is firmly connected around its periphery to the joint capsule and to the deep portion of the medial collateral ligament. Posteriorly, the medial meniscus connects to a

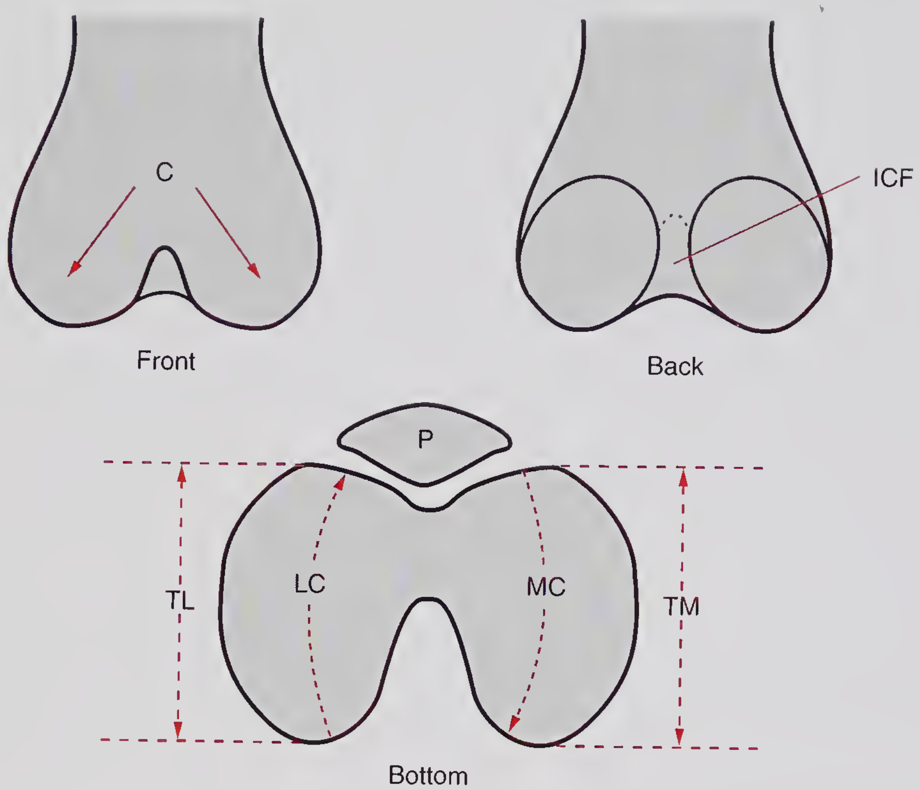


FIGURE 6.1

Femoral Condyles Femoral condyles (C) are convex structures at end of femur that are covered by cartilage on their rear surface. Between condyles is intercondylar fossa (ICF). Viewed from below, there is patellar (P) groove. It is apparent that total lengths of condyles are equal, but condylar surfaces on which there is gliding with concave surfaces of tibia differ in that medial meniscus is longer. LC and MC indicate lengths of condylar surfaces compared with total length of condyles (TL, lateral; TM, medial).

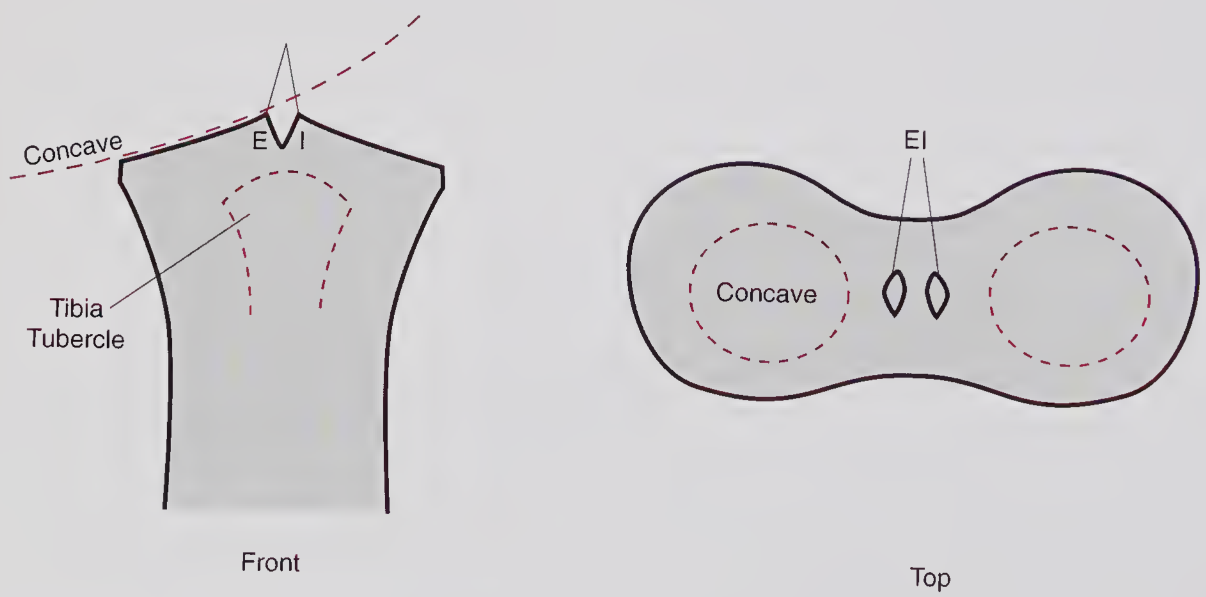


FIGURE 6.2

Tibial Articular Surface Front, Tibia with its concave surface that articulates with femoral condyles. EI indicates eminentia intercondylaris. Top, Two concavities and EIs.

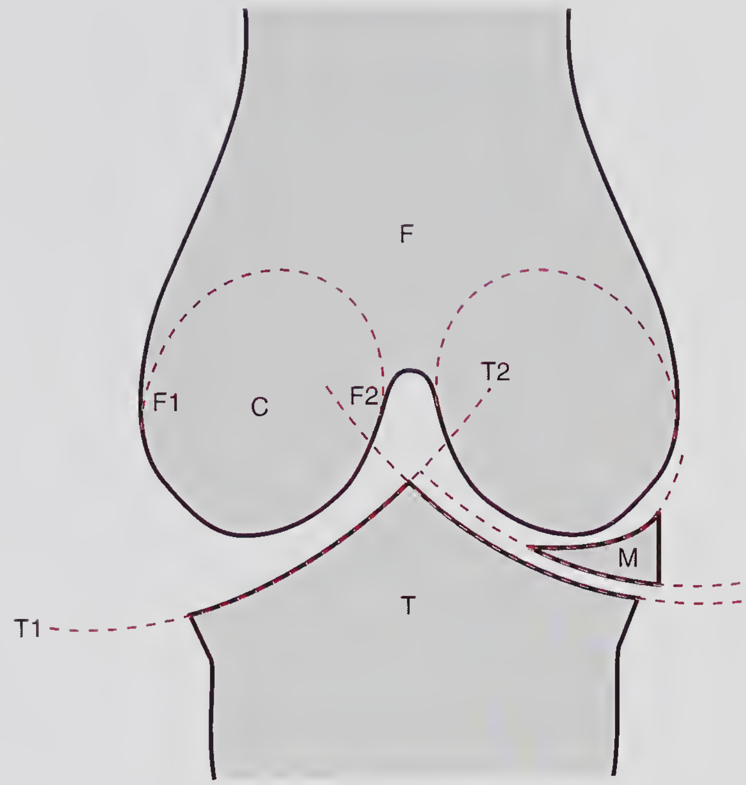


FIGURE 6.3

Congruity of Femoral-Tibial Joint Schematically, congruity is restored by presence of menisci. Femoral (F) condyles (C) have specific curvature (F1–F2), which is different from concavity of tibia (T) (T1–T2). Congruity is restored by curves of meniscus (M).

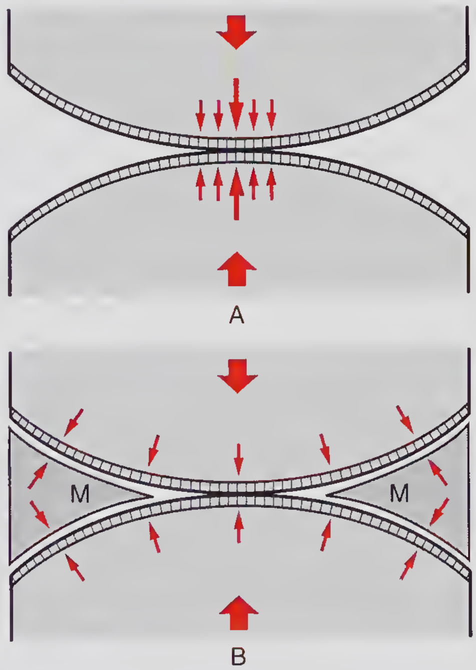


FIGURE 6.4

Weight Distribution Influenced by Menisci A, Without meniscus, weight is concentrated at middle of contact areas. B, Menisci (M) distribute weight along entire surfaces of tibial plateaus and femoral condyles.

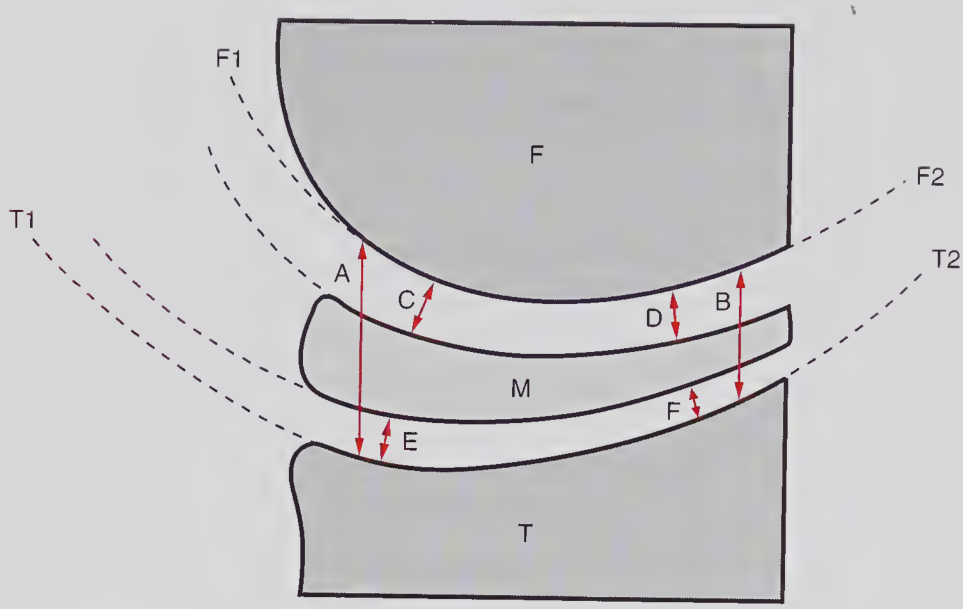


FIGURE 6.5

Hydrodynamic Lubrication of a Joint Nonparallel joint surfaces (F1–F2 and T1–T2) form wedge-shaped lubricating fluid, some of which stays at apex. (A is wider than B.) Lubricating fluid moves in layers A, B, C, D, E, and F at same speed as articulating bone surfaces. Shearing force between layers causes deformation of fluid. Lubricant is both adhesive and viscous, being coated by hyaluronic acid, which is created by synovium and cartilage. M indicates meniscus; T, tibia; and F, femur.

fibrous thickening of the capsule and to the tendinous portion of the semimembranous muscle.

The lateral meniscus has a width of 12 to 13 mm. Its curvature is greater than that of the medial meniscus, resembling a closed ring, whereas the medial meniscus is more C-shaped. Both anterior and posterior horns of the lateral meniscus attach directly to the eminentia intercondylaris spicules and to the posterior cruciate ligament by a fibrous connection (the meniscofemoral ligament). Most of the posterior horn inserts into the intercondylar fossa of the femur by a strong fascicle known as the ligament of Wrisberg, which blends with the posterior cruciate ligament.

The lateral meniscus has loose connections with the lateral capsule. At its posterior horn, the popliteal tendon interposes between the lateral meniscus and the capsule. By these connections, the lateral meniscus, which is not connected peripherally to the capsule, is able to rotate about its central connections to the tibial spines that act as a fulcrum (Figure 6.6).

The microscopic structure of the menisci must be understood to perceive any damage that may occur from abnormal stresses. The meniscus consists of 3 distinct zones of collagen fiber bundles. The outer one third of the meniscus is composed of circumferential fibers, and the other 2 layers have their fibers running in a transverse direction. These 2 inner zones are divided into superior and inferior bundles by a thin zone called the *middle perforating bundle* (Figure 6.7).

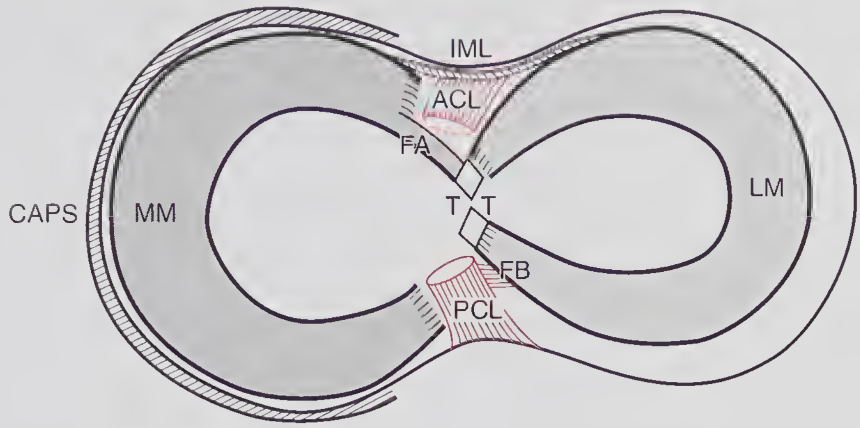


FIGURE 6.6

Meniscal Attachments Right tibial plateau viewed from above. Fibrous attachment (FA) of medial meniscus (MM) to outer ridge of tibial tubercle. Connection to anterior cruciate ligament (ACL) to intrameniscal ligament (IML), which attaches to anterior horn of lateral meniscus (LM). Medial meniscus is attached around its entire periphery to capsule (CAPS). Lateral meniscus (LM) has both its anterior and posterior horns attached to eminentia intercondylaris (TT) by fibrous band to posterior cruciate ligament (PCL). Fibrous band (FB) attaches superiorly into intercondylar fossa of femur.

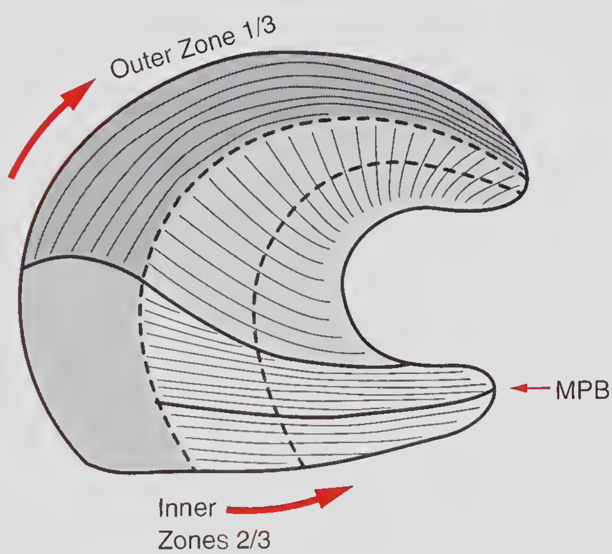


FIGURE 6.7

Microscopic Structure of Meniscus Meniscus is divided into 3 zones, each having 2 layers. Outer zone contains circumferential collagen fibers, and 2 inner zones contain collagen fibers that run transversely. Two zones are divided by thin layer of fibers termed *middle perforating bundle* (MPB).

Joint Stability

The static joint is made stable by virtue of the ligaments of the joint, as mechanical stability is not present in an incongruous joint. All the components of the knee joint need evaluation in determining stability (Figure 6.8).

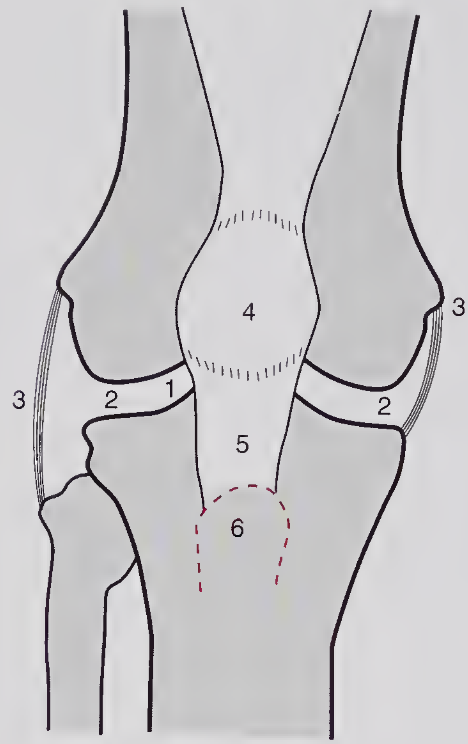


FIGURE 6.8

Sites of Components of Knee 1 indicates site of cruciate ligaments; 2, site of menisci; 3, collateral ligaments; 4, patella; 5, infrapatellar ligament; and 6, tibial tubercle.

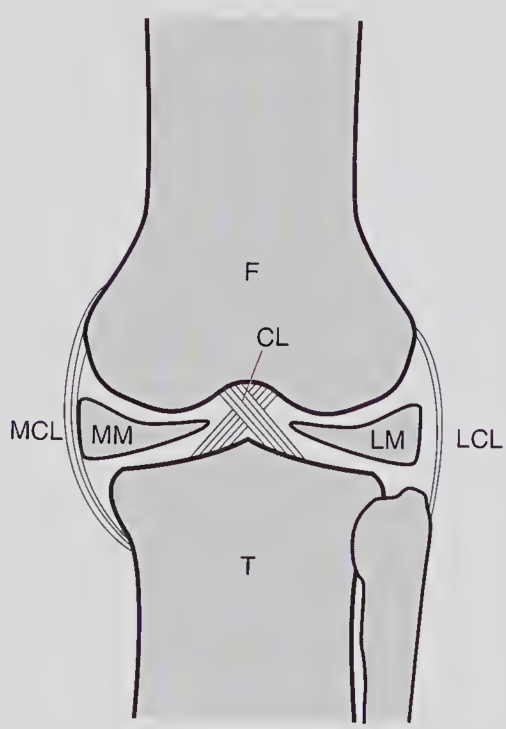


FIGURE 6.9

Ligaments of Knee Joint Femoral (F)-tibial (T) joint is stabilized by medial collateral ligament (MCL), lateral collateral ligament (LCL), and cruciate ligaments (CL). Menisci (medial, MM; lateral, LM) afford partial congruity.

As has been mentioned, the bony structure of the knee cannot, per se, afford stability; rather, stability is afforded by the ligamentous structures and the muscles of the joint (Figure 6.9).

Collateral Ligaments

Ligaments are similar in structure to tendons except that the arrangement of collagen fibers in ligaments is more irregular than they are in tendons, where they are more parallel. Ligaments also contain more elastin fibers within the collagen fibers. Microscopically, most ligaments have wavy, undulating patterns of collagen fibers that slowly straighten out when elongated by any load or force.

Ligaments are less readily recoverable after injury than are tendons, which have greater cellular components that are metabolically more active, contain fewer type III collagen fibers, and have more cross-linkage.

Ligaments at their attachments to bone merge into 3 zones: parallelism at zone 1, fibrocartilaginous in zone 2, and then mineralized in zone 3, where they blend into the bone. This blend causes greater "stiffness" of ligamentous attachment and explains why bony avulsion occurs more often than ligamentous tearing. Ligaments receive their blood supply from the vascularity of their sheaths (Figure 6.10).

Blood Supply to Femoral-Tibial Joint Structures

Five branches of the popliteal artery supply blood flow to the knee structures. The femoral artery originates from the iliac artery at the femoral triangle of the groin and descends anteriorly, branching into the deep arteria profunda femoris, which then branches into 4 perforating arteries (Figure 6.11).

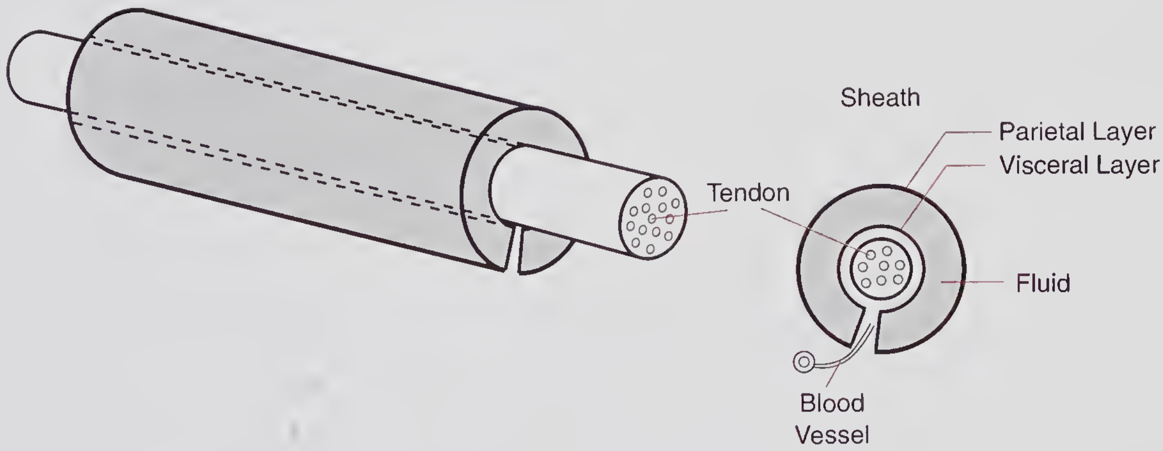


FIGURE 6.10

Vascular Supply to Tendons Sheath supplying blood supply to tendon shows how vessels enter sheath through linear cleavage between parietal and visceral layers of sheath, which contains synovial fluid.

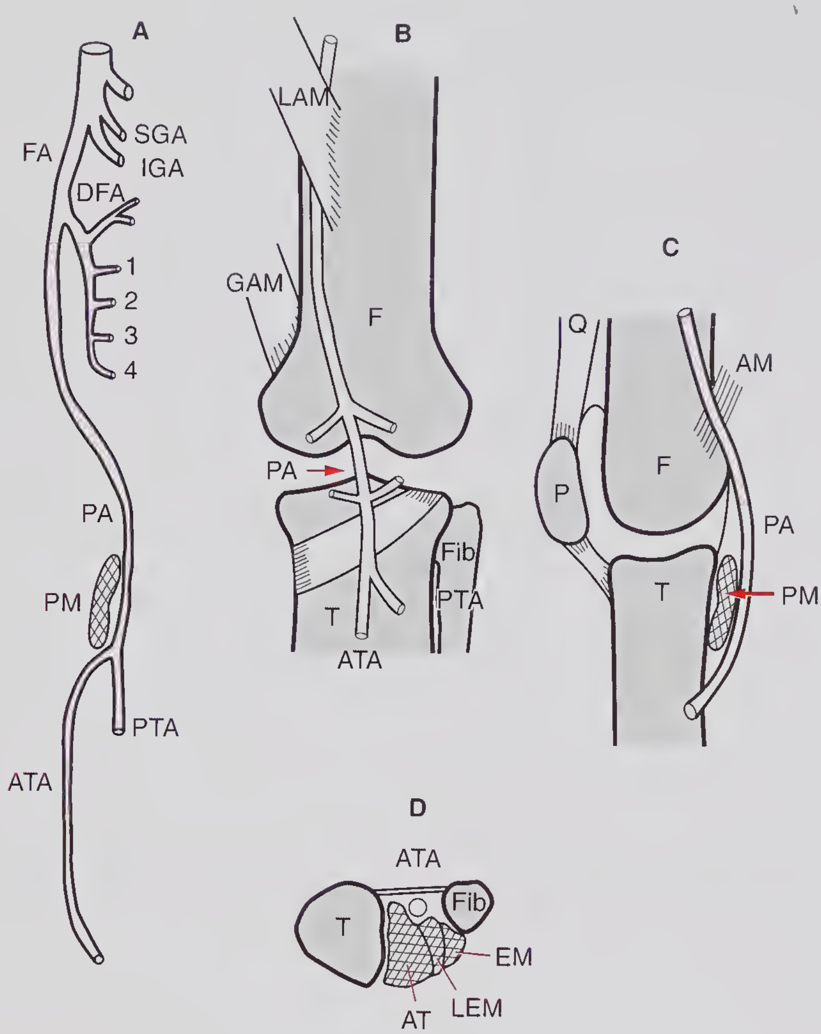


FIGURE 6.11

Femoral Artery Branches A, Schematic femoral artery branches throughout leg. B, Posterior aspect of knee. C, Lateral view of blood supply of knee. D, Superior view of anterior compartment of mid-leg region. F indicates femur; T, tibia; Fib, fibula; P, patella; LAM, long adductor muscle; GAM, great adductor muscle; PA, popliteal artery; ATA, anterior tibial artery; PTA, posterior tibial artery; SGA, superior gluteal artery; OGA, inferior gluteal artery; PFA, deep femoral artery; PM, popliteal muscle; TA, anterior tibial muscle; EHL, long extensor muscle of great toe; EDL, extensor muscle of toes; Q, quadriceps muscle.

When the popliteal artery approaches the popliteal space, it branches off into 2 superior genicular arteries, a central (middle) genicular artery, and below the space, 2 inferior genicular arteries. The superior genicular arteries curve around the femoral condyles and form a complex in the suprapatellar area anteriorly. The middle (central) rises from the posterior portion of the popliteal artery, pierces the popliteal ligament and sends 3 branches: the middle follows the anterior cruciate ligament and the other 2 entering the perimeniscal region to supply the menisci. The inferior genicular arteries course around the margin of the tibial plateau and pass under the collateral ligaments (Figures 6.12, 6.13).

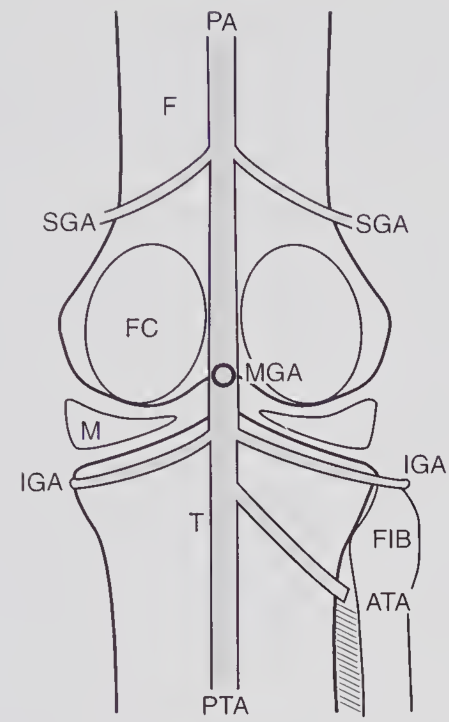


FIGURE 6.12

Geniculate Arteries Supplying the Knee Popiteal artery (PA) descends into popliteal space and divides into superior genicular arteries (SGA), middle genicular artery (MGA) and 2 inferior genicular arteries (IGA). F indicates femur; T, tibia; FC, femoral condyles; M, meniscus; FIB, fibula; and ATA, anterior tibial artery.

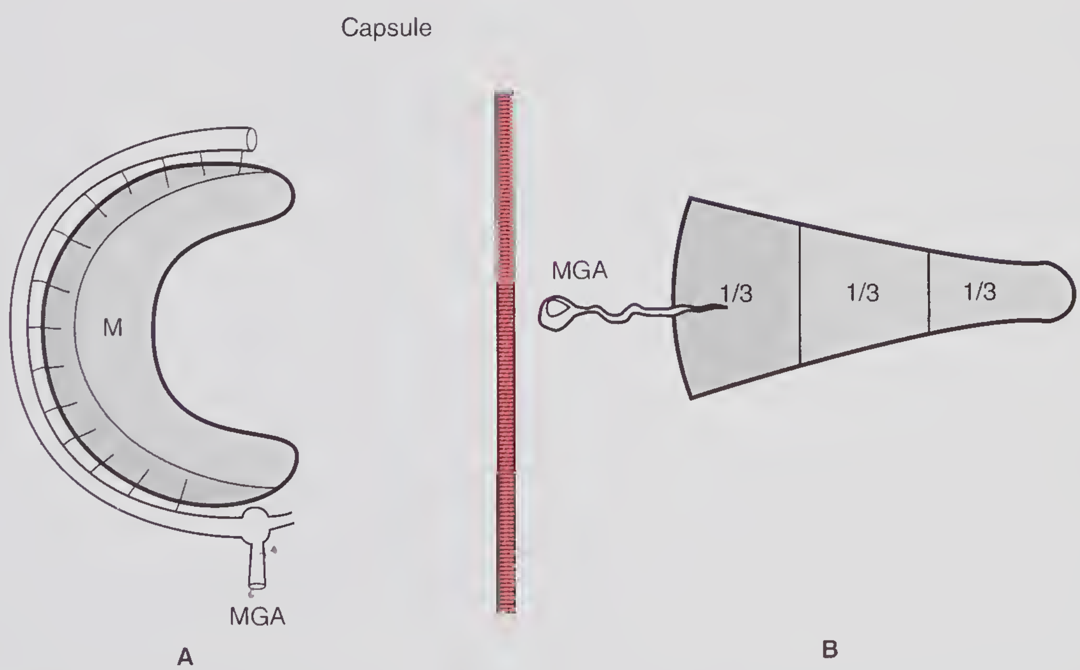


FIGURE 6.13

Intrinsic Circulation of Menisci A, Middle genicular artery (MGA) leading into circular artery about meniscus (M). B, Genicular artery entering outer one third of meniscus via tortuous arteriole. Inner two thirds of meniscus are avascular.

Capsular and Collateral Ligaments

The capsule of the femoral-tibial joint is a thin fibrous membrane that is formed into fascial ligamentous structures, which assist in stabilizing the knee joint. By their positions, they stabilize lateral and medial movement (varus-valgus) (Figure 6.14).

The medial collateral ligament consists of 3 fascial-like layers located on the medial aspect of the joint. It attaches superiorly to the femoral medial epicondyle and inferiorly to the tibia just below the level of the articular cartilage.

Layers 1 to 3 consist of deep crural fascia, superficial medial ligament, and the deep medial portion and the capsule, respectively. The superficial layer immediately under the skin is a fascial layer that also encloses the patella anteriorly and covers the popliteal fossa posteriorly. The sartorius muscle inserts directly on this fascia without a tendon. The gracilis and semitendinous muscle tendons invaginate the fascia.

Layer 2 is the superficial medial collateral ligament, which has vertical parallel fibers. The deeper capsular layer has 3 portions, and the middle segment has vertical parallel fibers and the anterior-posterior fibers curve. The anterior fibers attach to the extensor mechanism, and the posterior fibers to the popliteal capsule. The middle portion of layer 2 has been called both the medial collateral ligament and "the parallel fibers of the superficial medial ligament."[1]

The middle segment of the collateral ligament is further divided into 2 segments: the superior meniscofemoral segment, which fixes the medial meniscus, and the inferior meniscofemoral segment, which is loose and

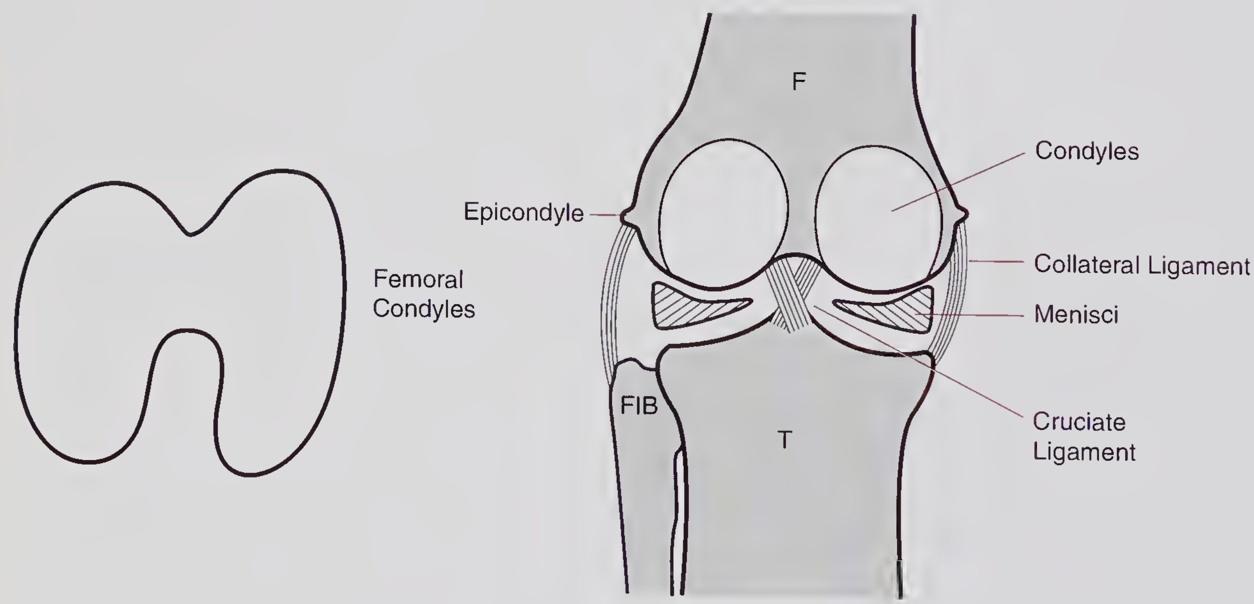


FIGURE 6.14

Ligaments of Femoral-Tibial Joint Knee joint and its collateral and cruciate ligaments, viewed posteriorly. FIB indicates fibula; F, femur; and T, tibia.

permits movement of the tibia on the meniscus. This will be discussed further in the section dealing with functional anatomy of the knee.

Layer 3 is the capsule, which may be a separate layer or merely a layer blending with the deep retinacular ligaments (Figure 6.15).

Lateral Collateral Ligaments

The lateral compartment of the knee joint extends posteriorly from the lateral margin of the patellar tendon (anteriorly) to the posterior cruciate ligament (posteriorly). It is divided into 3 bands extending from the lateral epicondyle of the femur to attach to the lateral aspect of the head of the fibula. The anterior aspect is the capsule extending from the extensor mechanism (patella and its tendons) to the iliotibial band.

The middle portion of the lateral collateral ligament is the iliotibial band. This tendon is divided into the meniscotibial and the meniscofemoral portions. The iliotibial band connects to the lateral epicondyle of the femur and to the lateral tubercle of the fibula. The posterior aspect of the iliotibial band is considered to be the lateral collateral ligament, which is ahead of the center of rotation of the femoral-tibial joint.

The posterior portion of the lateral compartment consists of interdigitating fibers of the capsule, called the *arcuate ligamentous complex*; this compartment contains the tendon of the popliteal muscle (Figure 6.16).

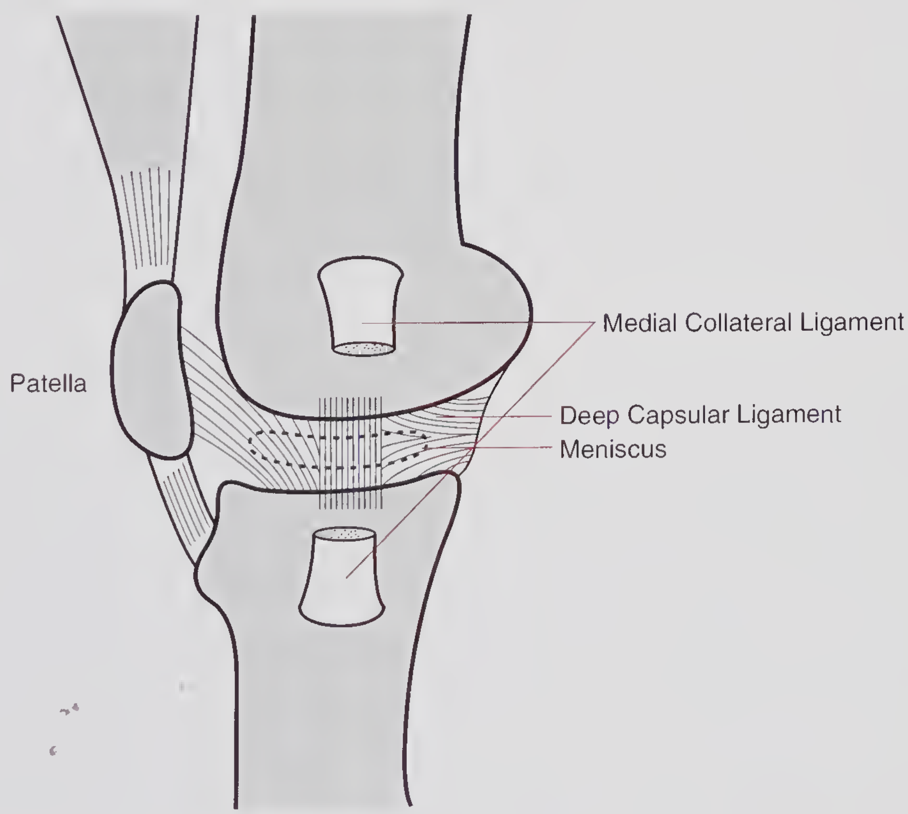


FIGURE 6.15

Medial Collateral Ligaments Medial collateral ligaments and their attachments.

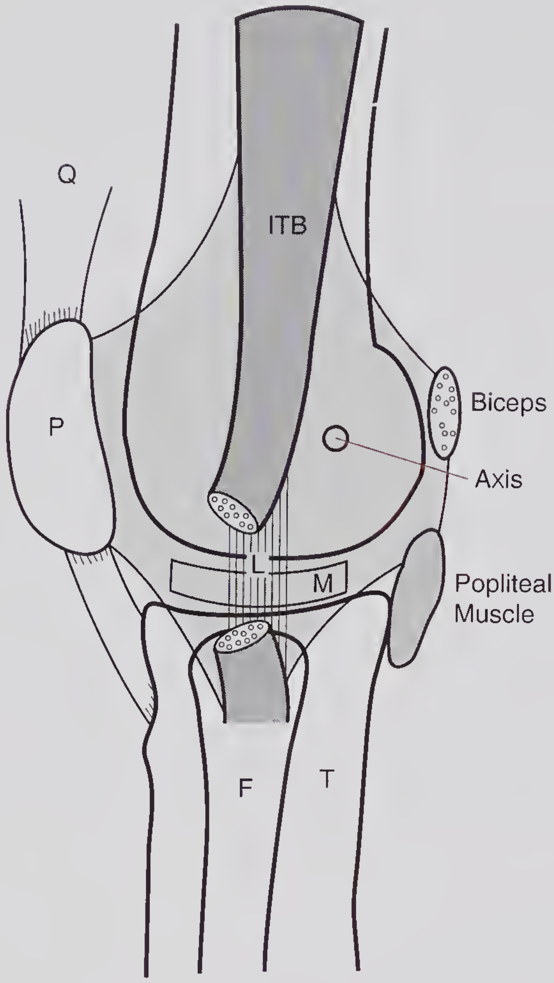


FIGURE 6.16

Lateral Collateral Ligament Tissues that form lateral collateral ligament. ITB indicates iliotibial band; Q, quadrate muscles; P, patella; F, fibula; T, tibia; L, lateral collateral ligament; and M, lateral meniscus. Axis is center of rotation of knee.

The popliteal muscle forms part of the floor of the popliteal fossa. It has 3 tendinous origins at the lateral epicondyle of the femur (Figure 6.17).

The arcuate ligament lies over the popliteal fascia and is firmly attached to it. The posterior fossa is bounded superiorly by the semimembranous and semitendinous muscles and the biceps tendon and inferiorly by the 2 heads of the gastrocnemius muscle. The roof of the fossa is the popliteal fascia. The peroneal nerve passes the neck of the fibula behind the biceps tendon. The fossa contains the popliteal artery, vein, and nerve, which divides into the peroneal and tibial branches. These branches pass over the lateral head of the gastrocnemius muscle and ultimately merge into a muscle belly, which, in turn, inserts via a tendon into the posterior proximal tibia (Figure 6.18).

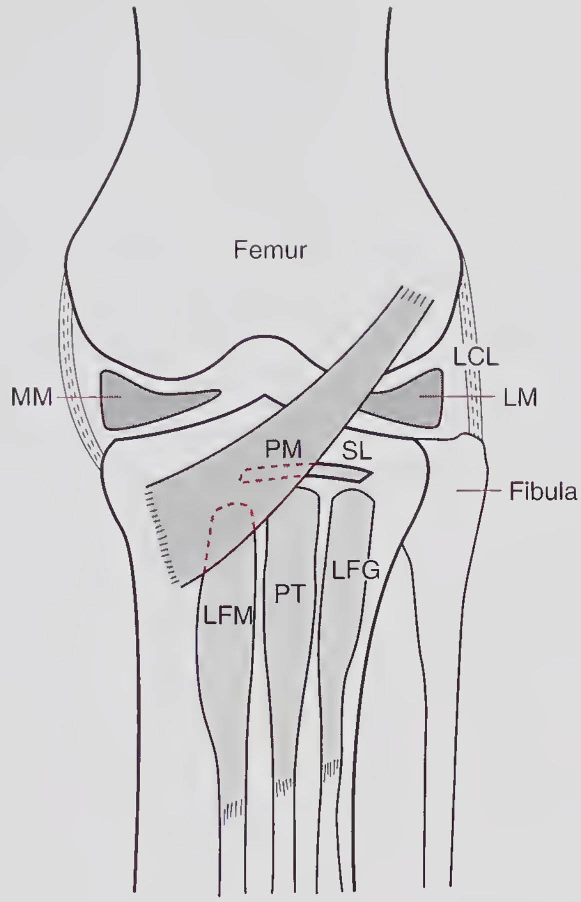


FIGURE 6.17

Popliteal Muscle Popliteal muscle (PM) originates from lateral epicondyle of femur under origins of gastrocnemius muscle and attaches to medial upper portion of tibia. It attaches superiorly to long flexor muscle of toes (LFM), posterior tibial muscle (PT), and long flexor muscle of great toe (LFG). MM indicates medial meniscus; LM, lateral meniscus; LCL, lateral collateral ligament; and SL, origin of soleus muscle.

The Cruciate Ligaments

There are 2 cruciate ligaments: anterior and posterior. The anterior cruciate ligament (ACL) arises from the nonarticular aspect of the tibia and passes superiorly, laterally, and posteriorly, to attach to the posterior portion of the intercondylar notch. It is considered anterior by virtue of its origin from the anterior portion of the tibia. It is long and firm. Many of its fibers attach to the anterior tip of the lateral meniscus, and an estimated 20% of its fibers reach posteriorly as far as the posterior origin of the lateral meniscus. It ultimately attaches to the posterior aspect of the medial surface of the lateral femoral condyle.

The ACL is composed of 2 bands: a small anteromedial band and a larger bulky posterolateral band, which travel parallel to each other and are

attached to each other by a soft material that permits them to move differently. A portion may remain inert while the other moves. Admittedly, the cruciate ligaments are essentially avascular, as are all ligaments, but the ACL receives it blood supply from the inferior and middle genicular arteries, with the synovium supplying the nutrition.

The tensile strength of the anterior cruciate ligament has been equated to that of the collateral ligaments but is half that of the posterior cruciate ligament.[2] In daily function, only half of the ligament functions at one time, while the other remains taut.

The posterior cruciate ligament (PCL) is an intra-articular-extrasynovial ligament inserting on the lateral surface of the medial femoral condyle. Its thinner posterior portion fans out on the posterior margin of the tibia. It, as has been stated, has twice the strength of the ACL.

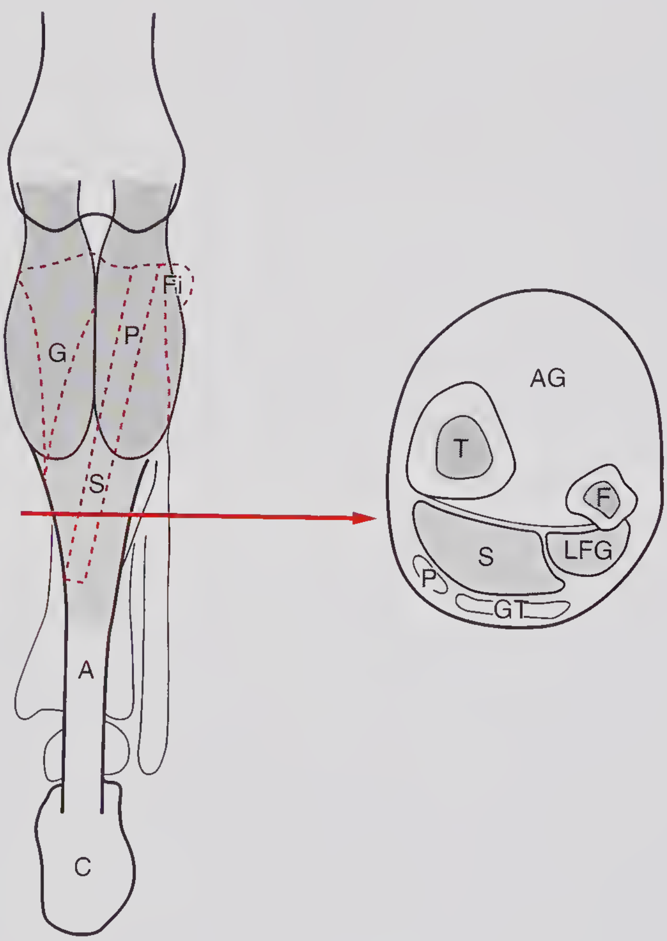


FIGURE 6.18

Posterior Musculature of Knee Popliteal muscle (P) lies under origin of gastrocnemius muscle (G). Left figure is view from above space. T indicates tibia; Fi, fibula; S, soleus muscle; A, Achilles tendon; C, calcaneus; AG, anterior muscle group; P, plantar muscle; LFG, flexor muscle of great toe; and GT, tendinous portion of gastrocnemius muscle.

THE PATELLAR-FEMORAL JOINT

The patella is a sesamoid bone contained within the quadriceps tendon. The quadriceps femoris tendon is made of 3 lamina: the superficial layer of the quadriceps femoris, the middle layer of the lateral and medial aspects of the femur (vastus medialis and lateralis), and the deep layer of the anterior and lateral surfaces of the femur (vastus intermedius). The superficial layer covers the anterior portion of the patella. The vastus medialis and lateralis attach to the middle (superior and lateral) aspect of the patella, and the vastus intermedius attaches to the posterior superior margin of the patella.

The nerve supply of the quadriceps is the femoral nerve, which is formed by the anterior primary division of L2 to L4 nerve roots. Besides being motor to the quadriceps, it furnishes a major cutaneous branch to the medial side of the leg and foot. The sensory divisions of the femoral nerve are the dermatomes of L2, L3, and L4.

Among the anterior thigh muscle group are the sartorius muscle and the tensor muscle of fascia lata. The sartorius muscle is a ribbonlike muscle that spirals across the thigh from its origin at the anterior superior spine, attaching to the anterosuperior medial portion of the tibia below the anterior tuberosity. Its action is weak flexion of the knee and hip. The tensor muscle of the fascia lata originates from the lateral aspect of the pelvis and descends along the lateral thigh region across the knee joint, where it forms a small portion of the lateral collateral ligament of the knee joint. Its function is to stabilize the lateral stability of the knee and to assist in knee extension (Figure 6.19).

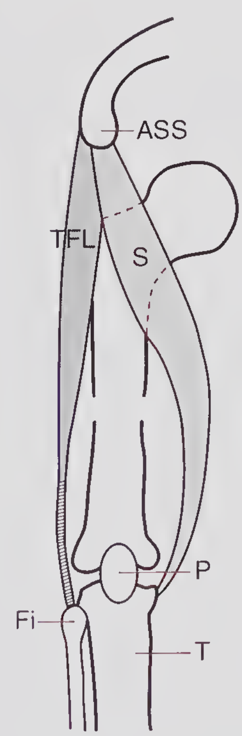


FIGURE 6.19

Sartorius Muscle and Tensor Fascia Lata Origin and insertion of sartorius muscle (S) and tensor muscle of fascia lata (TFL). ASS indicates anterior superior spine of iliac crest; P, patella; Fi, fibula; and T, tibia.

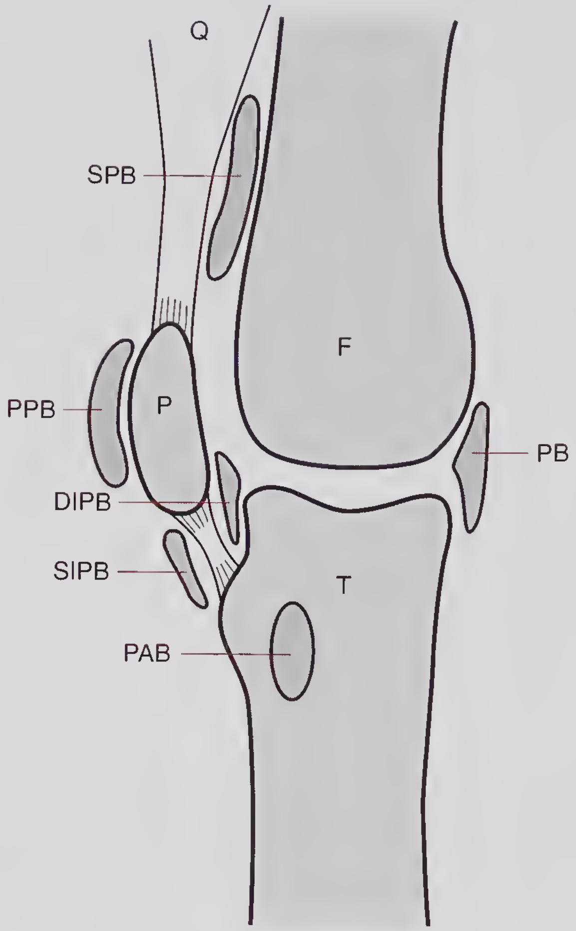


FIGURE 6.20

Bursae About Knee Joint These bursae surround knee joint: femur (F), tibia (T), quadriceps muscle (Q), patella (P), suprapatellar bursa (SPB), deep infrapatellar bursa (DIPB), prepatellar bursa (PPB), superficial infrapatellar bursa (SIPB), pes anserinus bursa (PAB), and popliteal bursa (PB), which may be a herniation of capsule.

There are numerous bursae about the knee joints that prevent friction and permit lubrication. A bursa is a sac containing synovial fluid located between tendons and ligaments (Figure 6.20).

THE FEMORAL-TIBIAL AND PATELLAR-FEMORAL JOINTS

Knee flexion and extension is a combination of rotation about the sagittal axis of the femoral condyles with a translatory gliding motion. As the knee flexes, the tibia glides posteriorly on the femoral condyles until it reaches the axis of rotation, then flexes. The femoral condyles viewed from the side are not totally round but are initially flat then round as the posterior portion is approached (Figure 6.21).

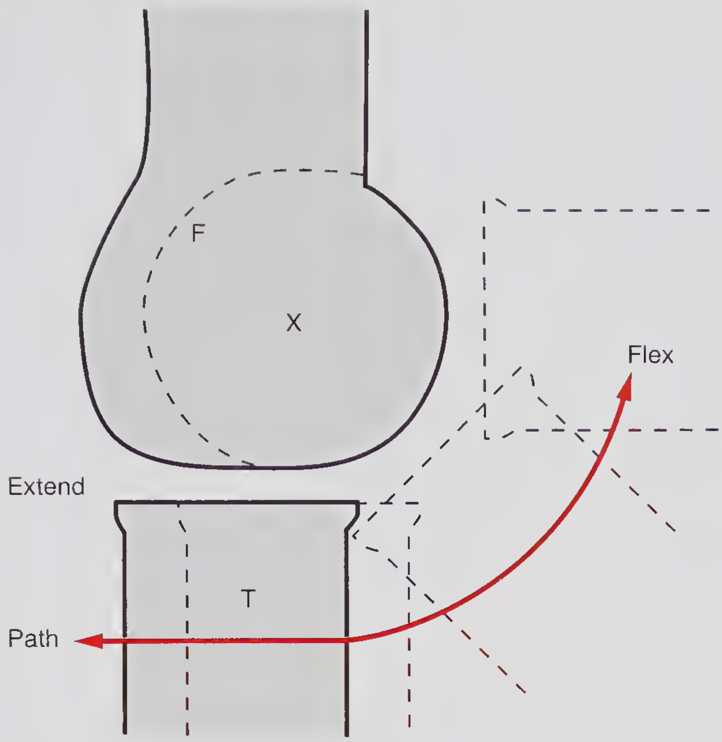


FIGURE 6.21

Sagittal Flexion-Extension of Femoral-Tibial Joint Tibia (T) flexes on femur (F) in path depicted. First degrees of flexion about femoral axis (X) are linear (horizontal) until tibia approaches center of rotation about condyles of femur; then it begins rotation (flexion).

LIGAMENTOUS CONTROL OF FLEXION-EXTENSION

The ligaments of the knee are essential for appropriate flexion-extension of the knee both in the sagittal plane and in the rotatory physiological flexion-extension.

The anterior cruciate ligaments prevent excessive extension and shear. After initial flexion along the horizontal plane and flexion about the axis begins, the posterior cruciate ligaments become the axis of rotation (Figures 6.22, 6.23).

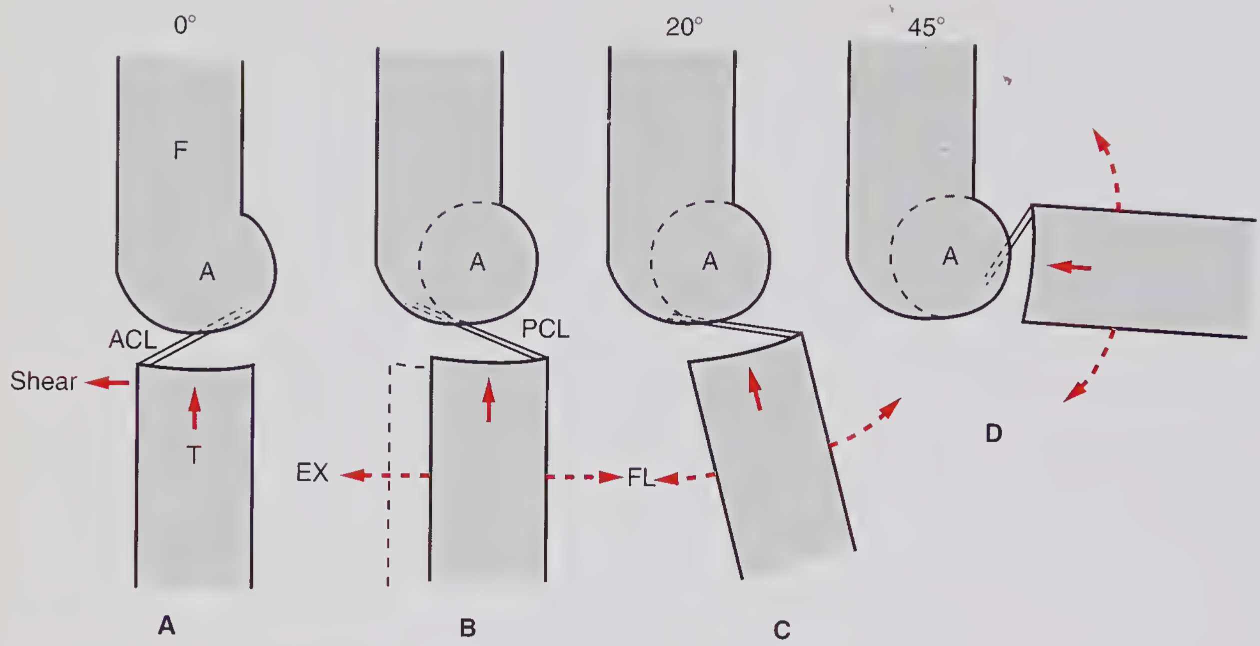


FIGURE 6.22

Action of Cruciate Ligaments on Knee Flexion-Extension A, Full knee extension of femur (F) on tibia (T). Anterior cruciate ligaments (ACL) prevent further anterior shear. B, After approximately 20 degrees of flexion (FL), tibia approaches center of rotation of femoral condyles and flexion begins. PCL indicates posterior cruciate ligament; EX, extension; and A, axis. C, Posterior cruciate ligament becomes axis of rotation (A), preventing further posterior shear and beginning rotation until 45 degrees of flexion is reached (D).

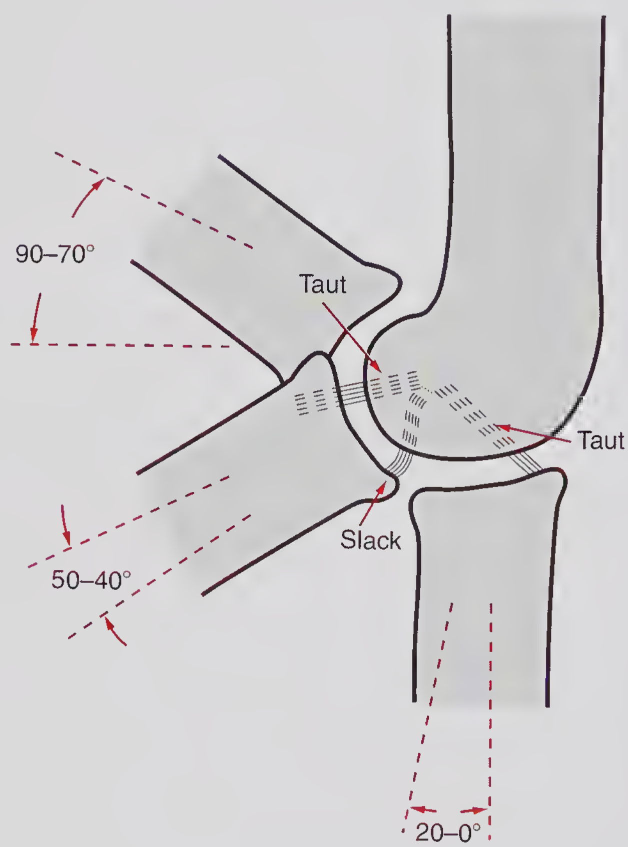


FIGURE 6.23

Anterior Cruciate Ligament During Flexion Anterior ligament is taut at full knee extension (0 degrees) and again at 70 to 80 degrees flexion.

COLLATERAL LIGAMENTS DURING FLEXION-EXTENSION

The medial and lateral collateral ligaments, which essentially prevent lateral and medial motion of the knee, also are involved in flexion-extension. At full extension, they are taut, being ahead of the axis of rotation and allowing no lateral-medial motion (varus-valgus) and no rotation. After 20 degrees of flexion, these ligaments become slack and permit some lateral medial motion but especially rotation of the tibia on the femoral condyles, which continues throughout all of knee flexion and extension (Figure 6.24).

During knee flexion and extension, there is usually simultaneous rotation of the tibia on the femur, with gradual internal rotation of the tibia during flexion, especially in the last degrees of flexion. In reextension, there is simultaneous external rotation of the tibia on the femoral condyles until full extension, when the tibia is externally rotated. What causes this simultaneous rotation is the relationship of the tibial plateaus on the femoral condyles as they glide on each other.

The articulating surfaces of the femoral condyles are longer than the anterior-posterior distances, which means that the tibia glides along a longer path on the medial condyles than on the lateral condyles. When the tibia has moved to the end of its glide on both condyles, the medial aspects has not been totally traversed. Further movement occurs, which can only be in a rotatory manner and to a limited degree, involving external rotation on further knee extension and internal rotation on further knee flexion (Figures 6.25, 6.26).

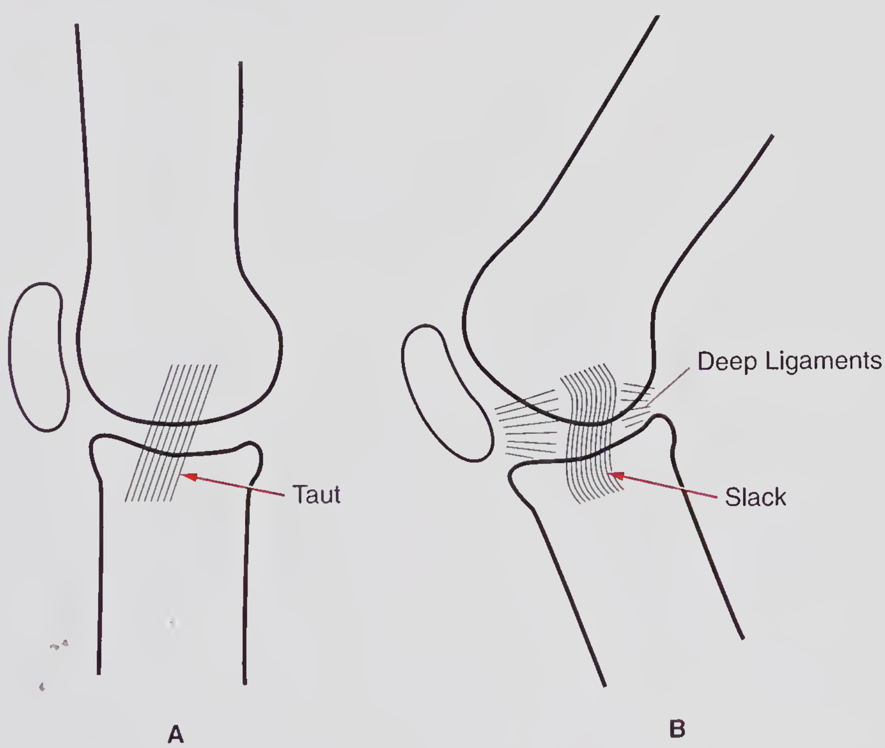


FIGURE 6.24

Tibial Collateral Ligaments During Knee Flexion A, At full knee extension, collateral ligament is taut. B, As knee flexes, ligament becomes slack and permits rotation and some lateral-medial varus-valgus motion.

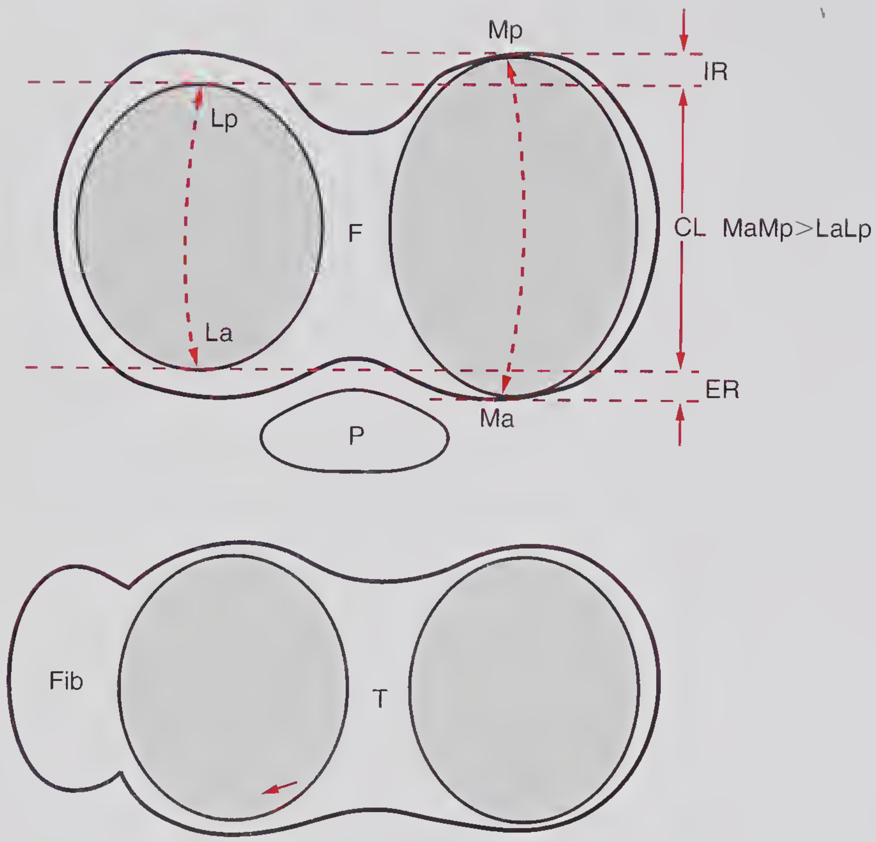


FIGURE 6.25

Articular Surfaces of Femoral Condyles Anterior-posterior lengths of both condyles (CL), with both being equal. LP–La indicates articular length of lateral condyles; Mp–Ma, length of lateral condyles, which is longer (MaMp>LaLp); IR, internal rotation surface that remains available; ER, external rotation; F, femur; and P, patella. Fib indicates fibula; T, tibia.

The degree of rotation of the tibia on the femoral condyles is limited by the ligaments of the femoral-tibial joint. The collateral ligaments have already been mentioned, and the cruciate ligaments are even more prominent in the rotatory control.

The cruciate ligaments limit the degree of anterior-posterior glide of the tibia on the femur and also limit the rotation. The anterior cruciate ligament uncoils during the first 15 to 20 degrees of flexion and external rotation. As further rotation occurs, the ligament becomes taut as it winds around the medial aspect of the lateral femoral condyle (Figures 6.27, 6.28).

Only certain portions of the cruciate ligament become involved during movement of the femoral-tibial joint motion. The ligament is divided into the larger, bulkier posterolateral band (PLB) and the smaller anteromedial band (AMB), which runs parallel to the other band. A part of each band remains relaxed and another part is tense throughout the full range of motion, but there is a portion that remains taut throughout all motions. The AMB remains taut from 70 degrees of flexion to full flexion and furnishes 85% of the resistance to anterior translation at 90 degrees of knee flexion. The PLB is taut at full extension and during the first 40 to 50 degrees of flexion. At 40 to 50 degrees of flexion, both bands are relaxed, and it is at the stage of flexion that anterior shear is most prominent. Both bands restrict rotation.

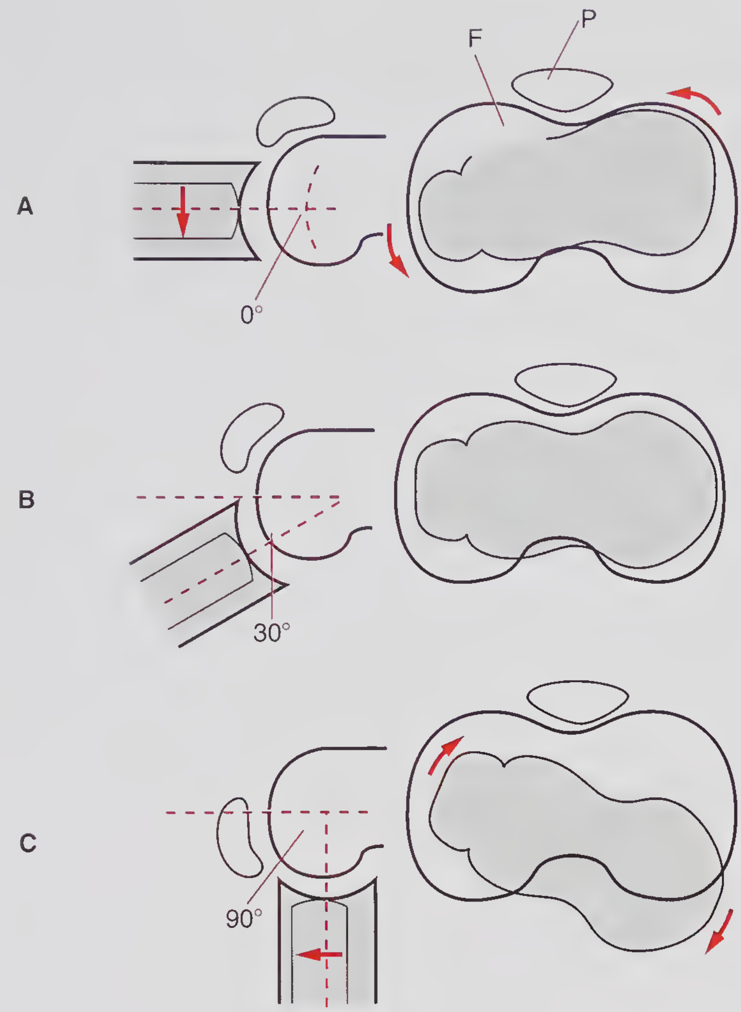


FIGURE 6.26

Rotation of Tibia on Femur A, At full knee extension (0 degrees), tibia is externally rotated (curved arrows). B, At 30 degrees flexion, tibia and femur (F) are in equal alignment. C, At 90 degrees flexion, tibia has rotated internally. P indicates patella.

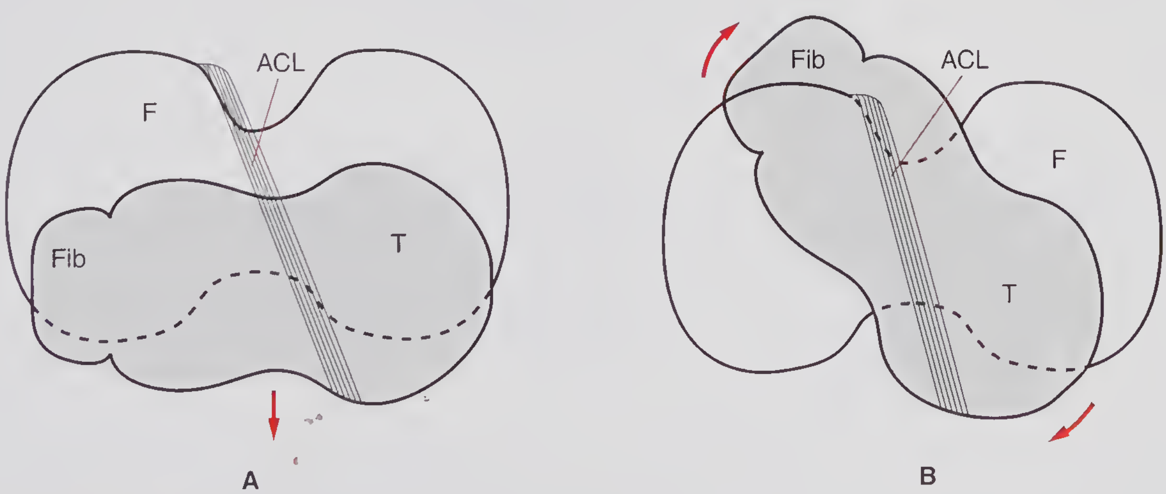


FIGURE 6.27

Cruciate Limits of Anterior-Posterior Glide and Rotation Anterior cruciate ligament (ACL) originates from anteromedial aspect of tibia (T) and inserts into posteromedial aspect of lateral femoral condyle (F). A, Anterior-posterior glide (arrow) of tibia and fibula (Fib) on femoral condyles limited by anterior cruciate ligament. B, Limitation of external rotation (curved arrows) by ACL.

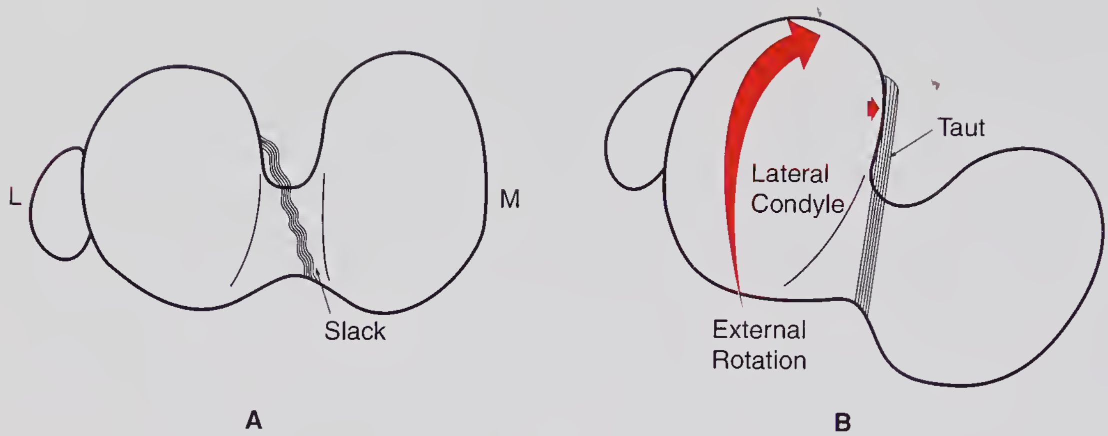


FIGURE 6.28

Anterior Cruciate Ligament Action A, Anterior cruciate ligament is slack when there is no rotation or anterior-posterior glide. B, As external rotation occurs, anterior cruciate ligament becomes taut. L indicates lateral; M, medial.

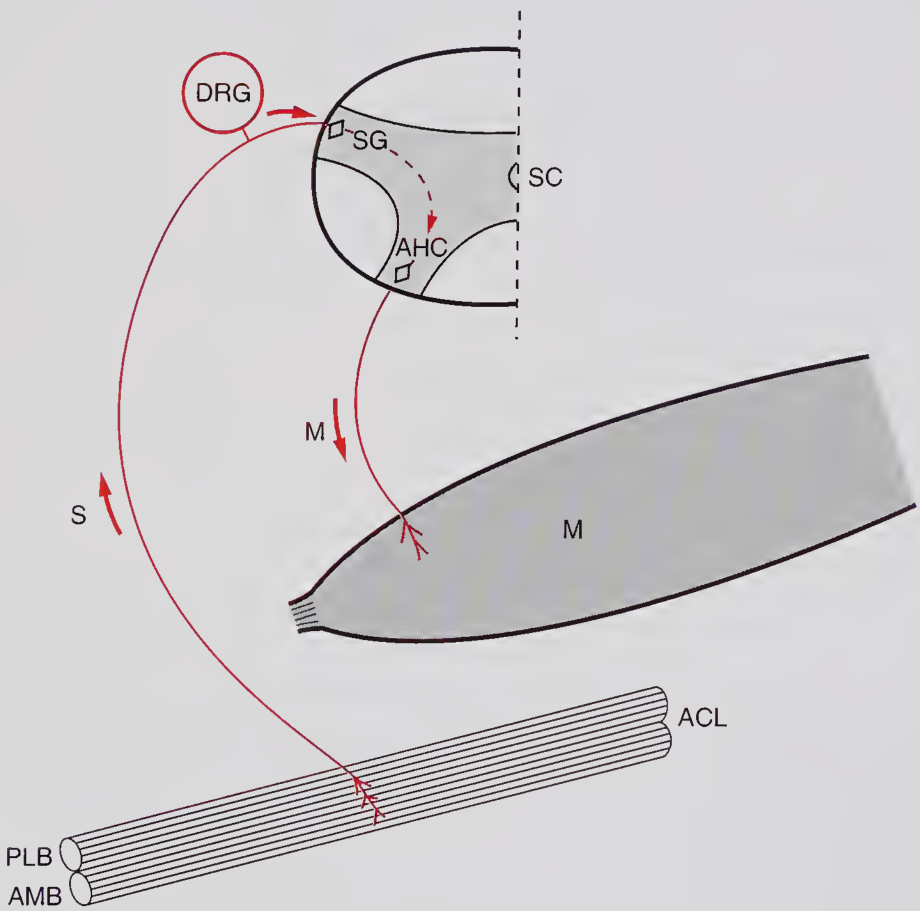


FIGURE 6.29

Proprioceptive Innervation of Anterior Cruciate Ligament Anterior cruciate ligament (ACL) is formed of 2 parallel bands: bulkier posterolateral band (PLB) and smaller, thinner parallel band called anteromedial band (AMB). It is postulated that there are proprioceptive afferents (S arrow) that enter spinal cord (SC) through dorsal root ganglion (DRG), entering substantia gelatinosum (SG). Anterior horn cell (AHC) is activated and innervates (M arrow) muscles (M) where spindle system and Golgi apparatus moderate intensity of muscular contraction.

By their innervation, the cruciate ligament bands supply feedback to the neuromuscular system, influencing knee function (Figure 6.29).

The resultant muscular contraction of the knee joint is moderated by the tension apparently imposed on the cruciate ligament. The ligaments contain nerve endings resembling Ruffini endings and Pacinian corpuscles that probably send proprioceptive impulses to the muscles. These endings are located at the endings of the ligament. Similar nerve endings have been found in the posterior cruciate ligaments.

Motion of the Menisci

The menisci are essentially attached to the tibia by the collateral ligaments and therefore move with the tibia in all knee motions. The medial meniscus is attached to the medial collateral ligament around its entire periphery, and both horns of the medial meniscus are attached to the tibial tubercle. The lateral meniscus does not have peripheral attachments to the lateral collateral ligament but is also attached centrally to the tibial tubercle.

As the knee flexes and reextends, the meniscus moves with the tibia in flexion-extension and simultaneous rotation (Figure 6.30).

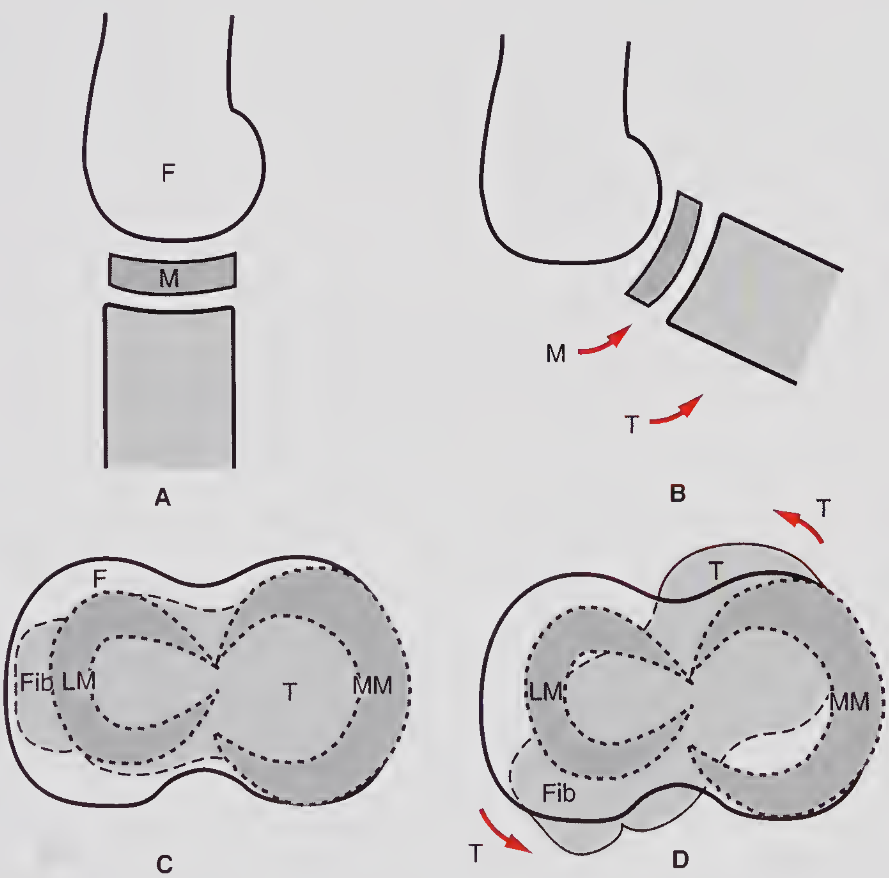


FIGURE 6.30

Movement of Menisci in Knee Motions A and C, Position of meniscus (M) in full knee extension. B, Movement of meniscus (M) with flexion (curved arrows). D, In simultaneous rotation, meniscus remains with femoral condyles and does not accompany tibia (T). F indicates femur; Fib, fibula; LM, lateral meniscus; and MM, medial meniscus.

MUSCULAR ACTION ON KNEE-JOINT MOTION

The major muscles acting on the knee joint are the 4 heads of the quadriceps femoris known as the extensor mechanism. The 4 components are the rectus femoris, the vastus medialis, the vastus lateralis, and the vastus intermedius (Figure 6.31). The rectus femoris originates as a tendon from the inferior iliac crest of the pelvis, which lies immediately superficial to the iliofemoral ligament (Figure 6.32).

The alignment of the quadriceps muscles as they cross the femur form an angle with the vertical called the Q angle. These lines forming the angle are drawn with one originating at the anterior-superior iliac crest through the midline of the patella and the other from the tibial tubercle through the midpoint of the patella (Figures 6.33, 6.34, 6.35).

The sartorius muscle and the tensor muscle of fascia lata are considered anterior thigh muscles. The sartorius, as mentioned earlier, originates from

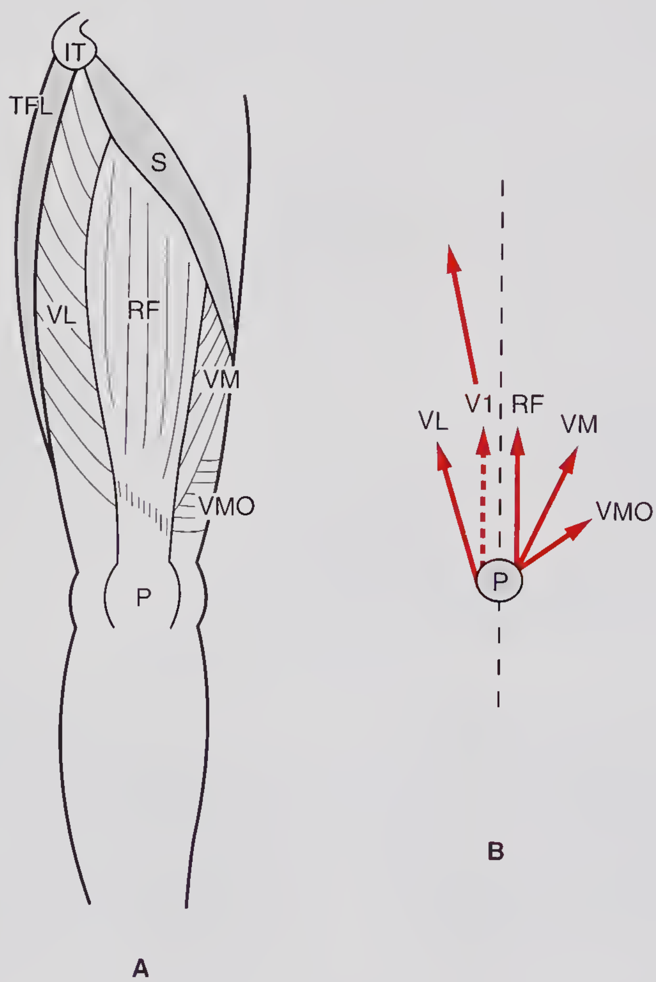


FIGURE 6.31

Musculus Quadriceps Femoris Muscles of extensor mechanism are shown as are their lines of pull on knee joint. A, Rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), and vastus medius obliquus (VMO). TFL indicates tensor muscle of fascia lata, and S indicates sartorius muscle, which are not in extensor mechanism. IT indicates iliac tuberosity; P, patella. B, Lines of pull as related to center of gravity (dotted lines). V1 indicates vastus intermedius.

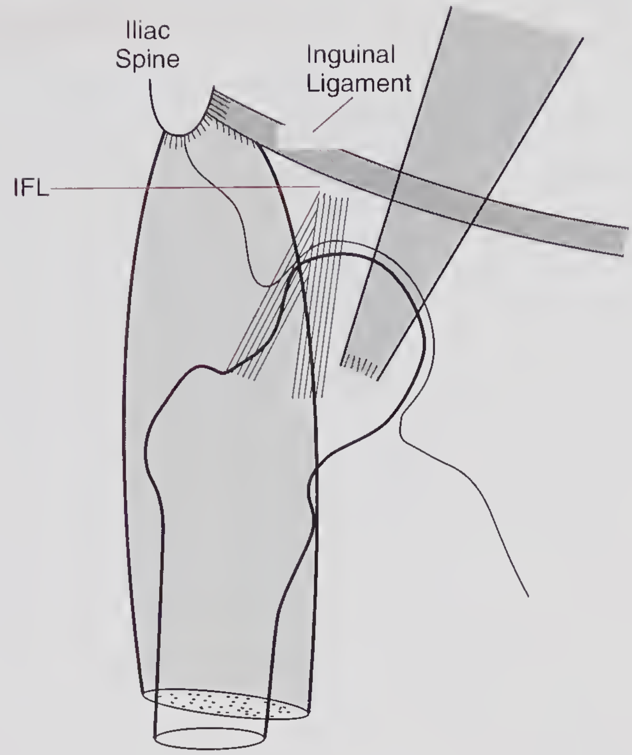


FIGURE 6.32

Origin of Rectus Femoris Musculus rectus femoris originates as a tendon from inferior iliac crest of pelvis from which also originates inguinal ligament. It overlies iliofemoral ligament (IFL) and descends over hip joint.

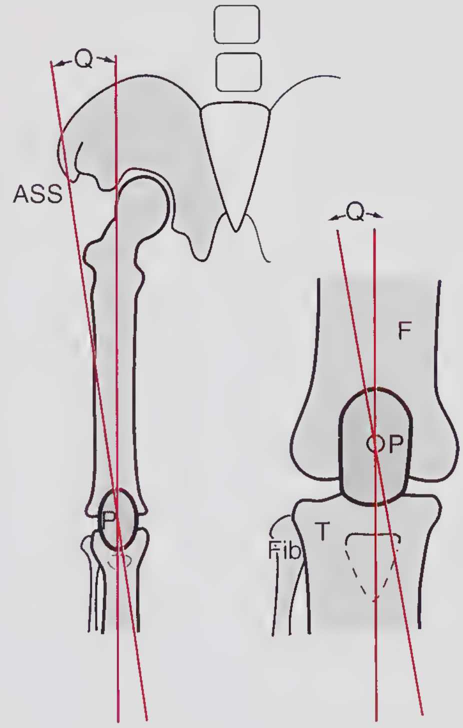


FIGURE 6.33

Q Angle Q angle is drawn from 2 intersecting lines. One line is from anterior superior spine of iliac crest (ASS) crossing patella (P) at midpoint. Other line is vertical through midpoint of patella. F indicates femur; T, tibia; and Fib, fibula.

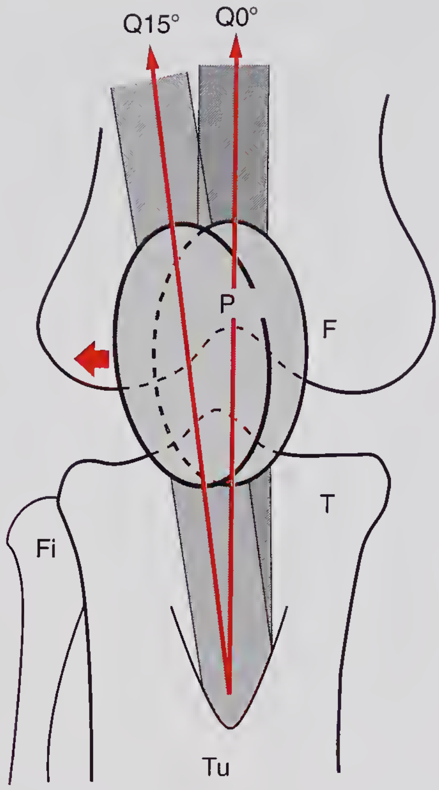


FIGURE 6.34

Lateral Patellar Pull As quadriceps pulls patella (P) at Q angle of approximately 15 degrees, some muscular action is needed to maintain its centrality (large arrow). F indicates femur; T, tibia; Fi, fibula; and Tu, tibial tubercle.

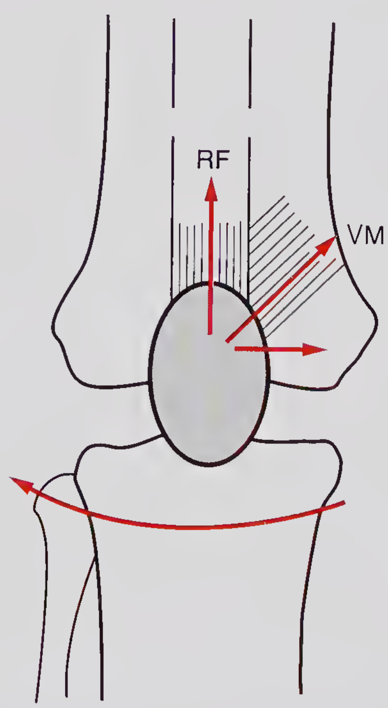


FIGURE 6.35

Vastus Medialis Pull on Patella Vastus medialis (VM) pulls patella upward and medially, thus partially neutralizing Q-angle pull. RF indicates rectus femoris.

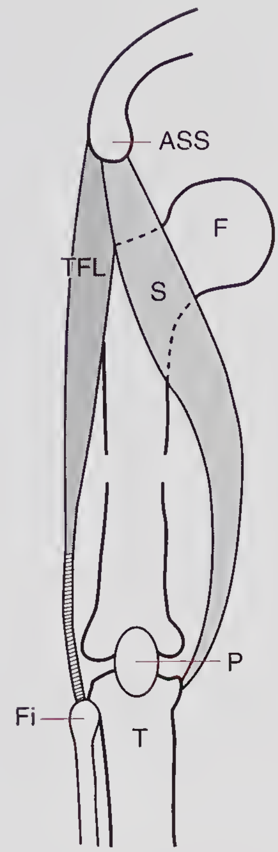


FIGURE 6.36

Sartorius Muscle and Tensor Muscle of Fascia Lata Sartorius (S) is weak flexor muscle of knee and hip. Tensor muscle of fascia lata (TFL) is considered a knee extensor but basically adducts and stabilizes hip joint. ASS indicates anterior superior spine of iliac crest; F, femur; T, tibia; Fi, fibula; and P, patella.

the anterior superior iliac crest and descends in a spiral manner down the anterior thigh, to insert on the anterosuperior portion of the tibia below the anterior tuberosity. The tensor muscle of fascia lata originates from the lateral aspect of the pelvis and descends along the lateral thigh region across the knee, to attach to a portion of the lateral collateral ligament of the knee. It assists the fully extended knee in acquiring stability (Figure 6.36).

The Patellar-Femoral Articlator

The patella is a sesamoid bone contained within the quadriceps infrapatellar ligament. Viewed laterally, the quadriceps can be envisioned as pulling the patella directly vertically and not placing knee extension forces in a physiological direction to extend the knee joint. The lines of force allowing the quadriceps to extend the knee joint are because of the fulcrum afforded by the patella (Figure 6.37).

Patellar Movement During Knee Movement

The facets of the patella make contact on the femoral condyles at various degrees of knee flexion (Figure 6.38).

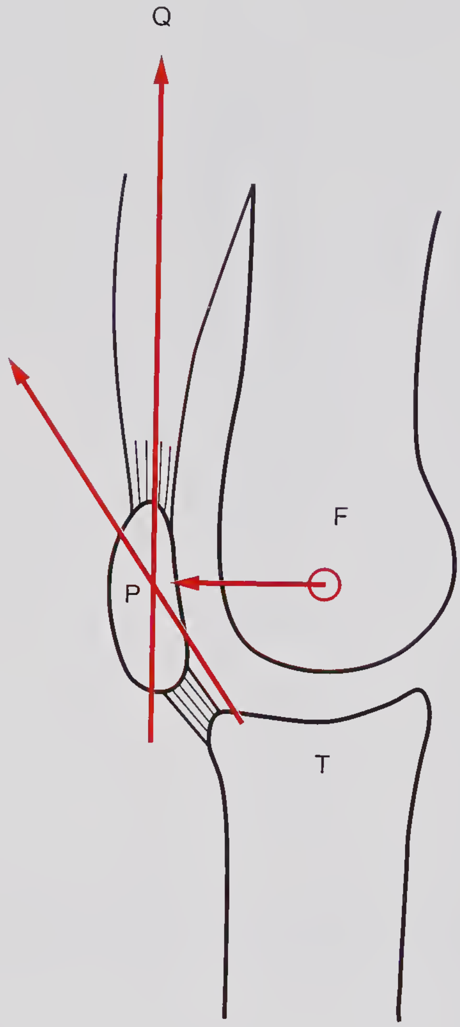


FIGURE 6.37

Fulcrum Pull of Extensor Mechanism from Patella Patella (P) is distance from axis of rotation of knee joint. Vertical pull of quadriceps (Q) due to patella causes force (oblique arrow) to pull tibia horizontally in a shear manner. F indicates femur; T, tibia.

At 20 degrees of flexion, there is slight contact of the upper portion of the patella with the femoral condyles. By 45 to 50 degrees of knee flexion, the middle facets of the patella make major contact, and at full flexion (90 degrees) all contact is on the inferior lateral facet. The odd facet does not make contact until 135 degrees of flexion, and the medial facets also make contact after 135 degrees, when the tibia and femur have rotated (Figures 6.39, 6.40, 6.41, 6.42, 6.43).

In the retinaculum, which also guides the movement of the patella within the femoral condyles, resides the small nerve that probably transmits proprioception and nociception (Figure 6.44).

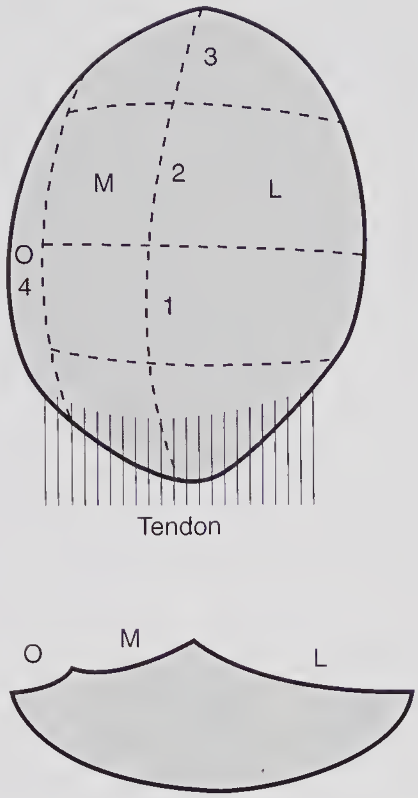


FIGURE 6.38

Facets of Patella Inner cartilaginous surface of patella is divided into numerous facets. Lateral half (L) is broader than medial half (M) and is divided into 3 facets. Inferior facet attaches to infrapatellar tendon. Halfway on medial half is odd facet (O). Lower illustration shows patella from a superior view.

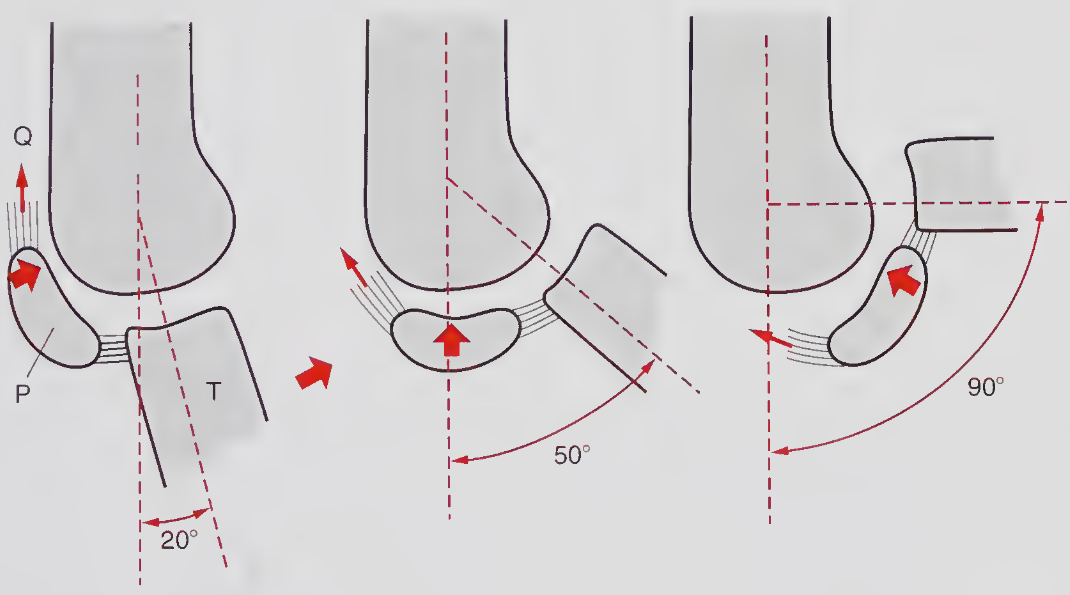


FIGURE 6.39

Patellar Contact on Femoral Condyles When knee flexes to 20, 50, and 90 degrees, arrows indicate where contact is made on femoral condyles. P indicates patella; T, tibia; and Q, vertical pull of quadriceps muscle.

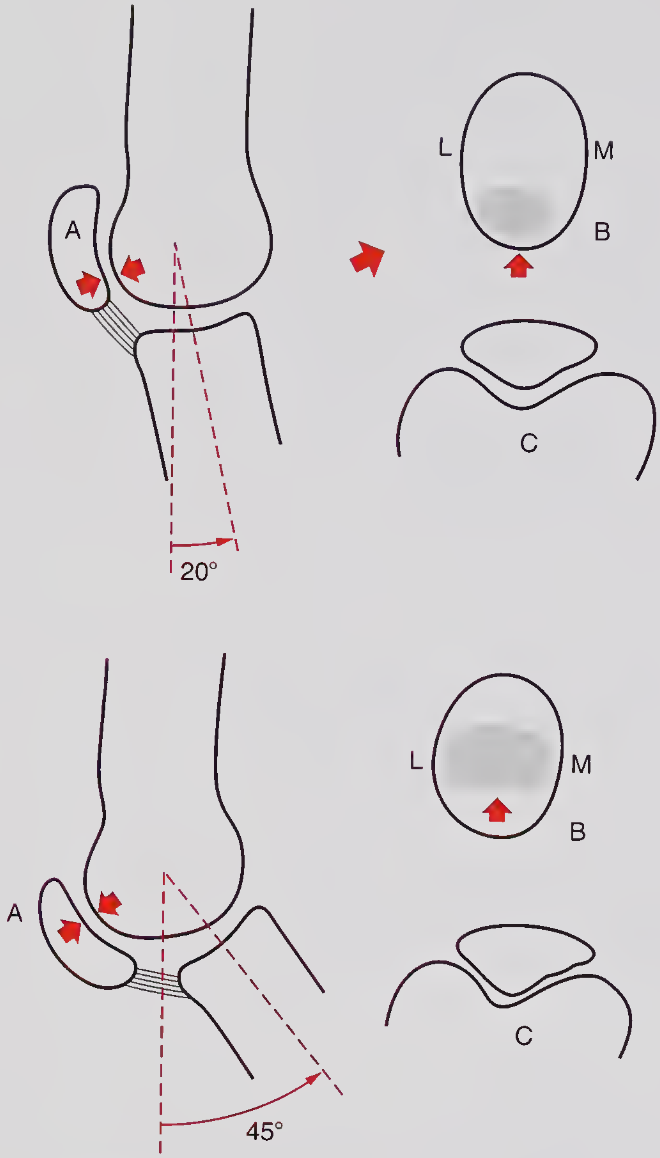


FIGURE 6.40

Sites of Patellar Contact With Knee Flexion Top, A, B, and C show patellar contact at 20 degrees of knee flexion. Bottom, Sites of contact at 45 degrees of knee flexion. L indicates lateral; M, medial.

Physiological, passive patellar movements are numerous and frequently determined clinically, so to avoid considering these movements as pathological, deserve attention (Figures 6.45, 6.46).

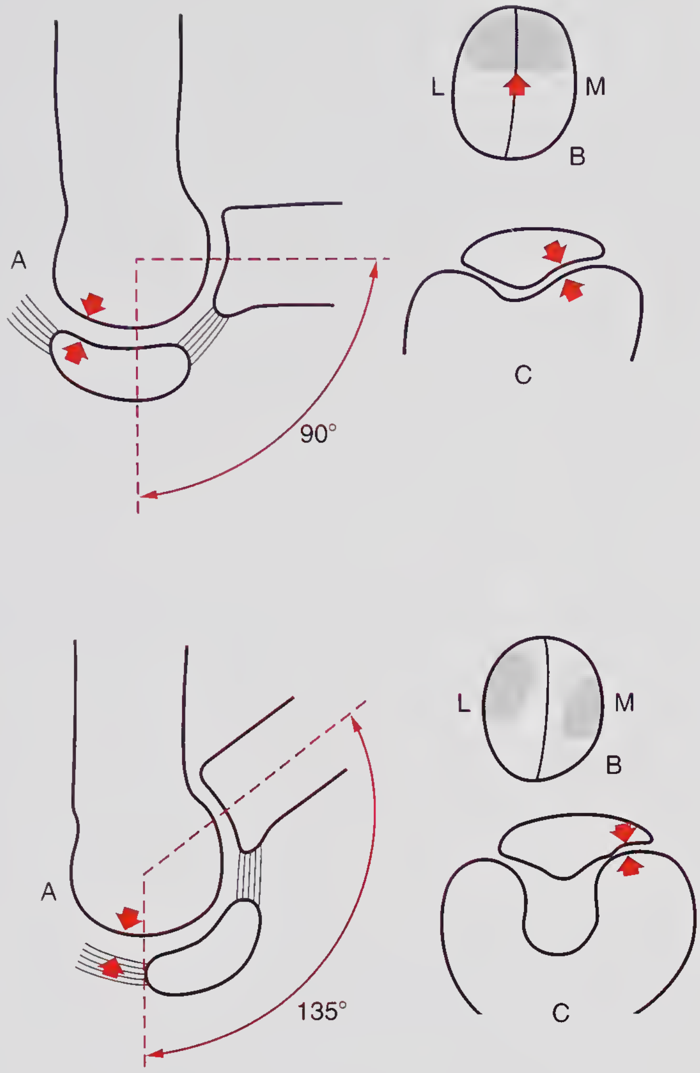


FIGURE 6.41

Sites of Patellar Contact at 90 and 135 Degrees of Knee Flexion Sites of patellar contact with condyles at 90 and 135 degrees of knee flexion. L indicates lateral; M, medial.

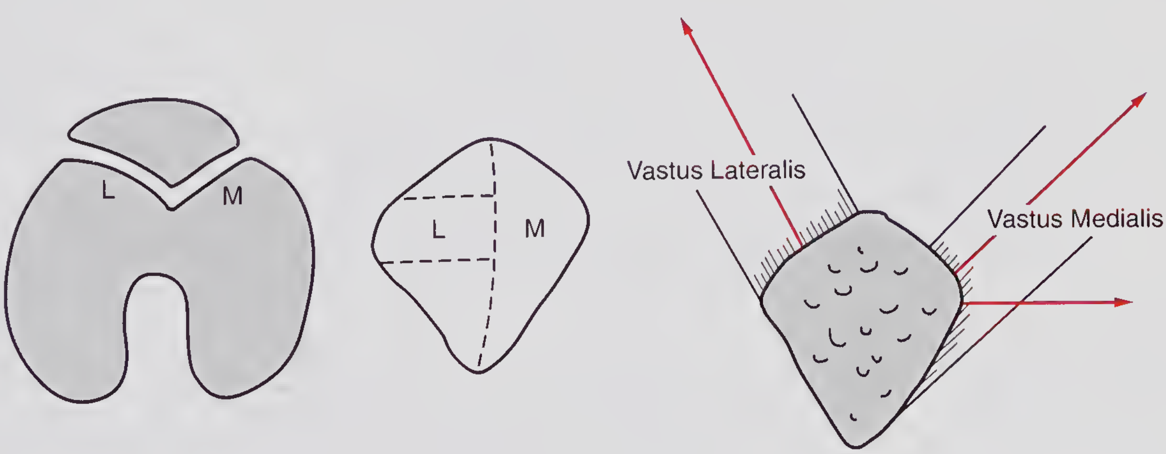


FIGURE 6.42

Muscular Action Affecting Patellar Contact Muscles acting on patella and their direction of pull. L indicates lateral; M, medial.

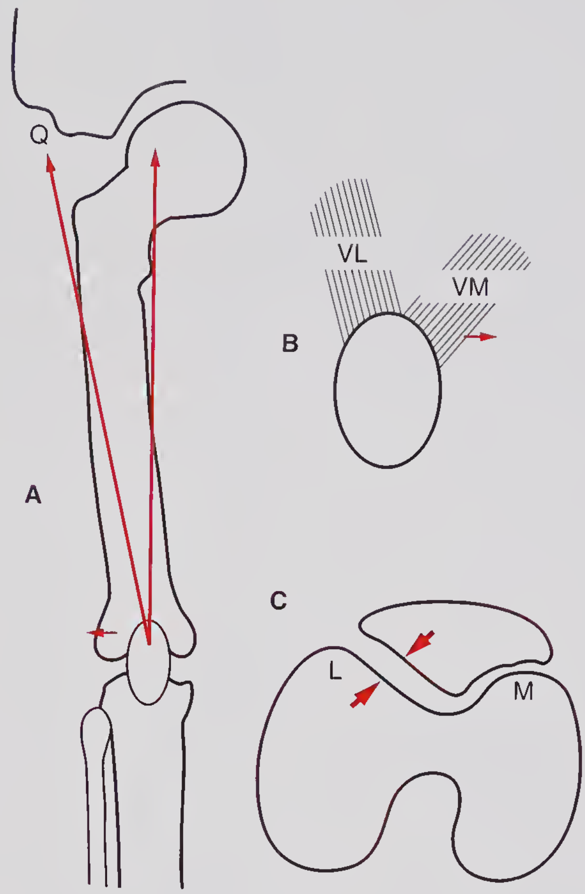


FIGURE 6.43

Effect of Q Angle on Patellar Pull Q-angle pull of quadriceps (A) pulls patella laterally (C), causing contact on lateral (L) femoral condyles. B indicates muscles that correct some lateral pull; M, medial; VL, vastus lateralis; and VM, vastus medialis.

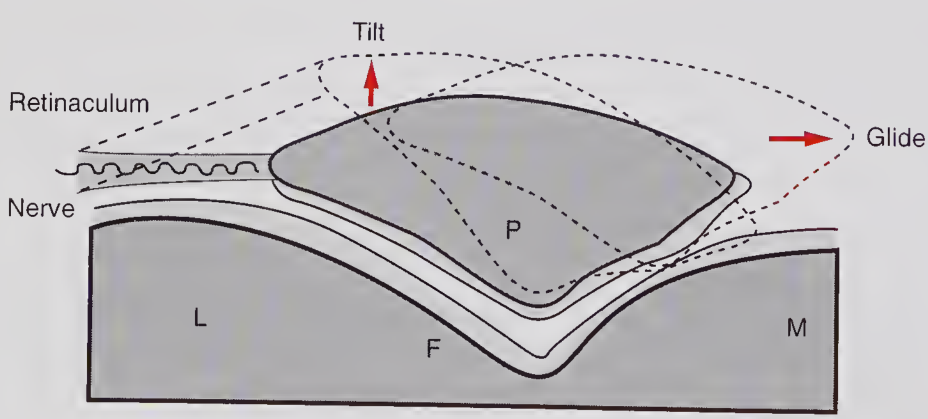


FIGURE 6.44

Innervation of Retinaculum Nerve enters patellar mechanism via retinaculum. Various normal passive motions of patella are indicated.

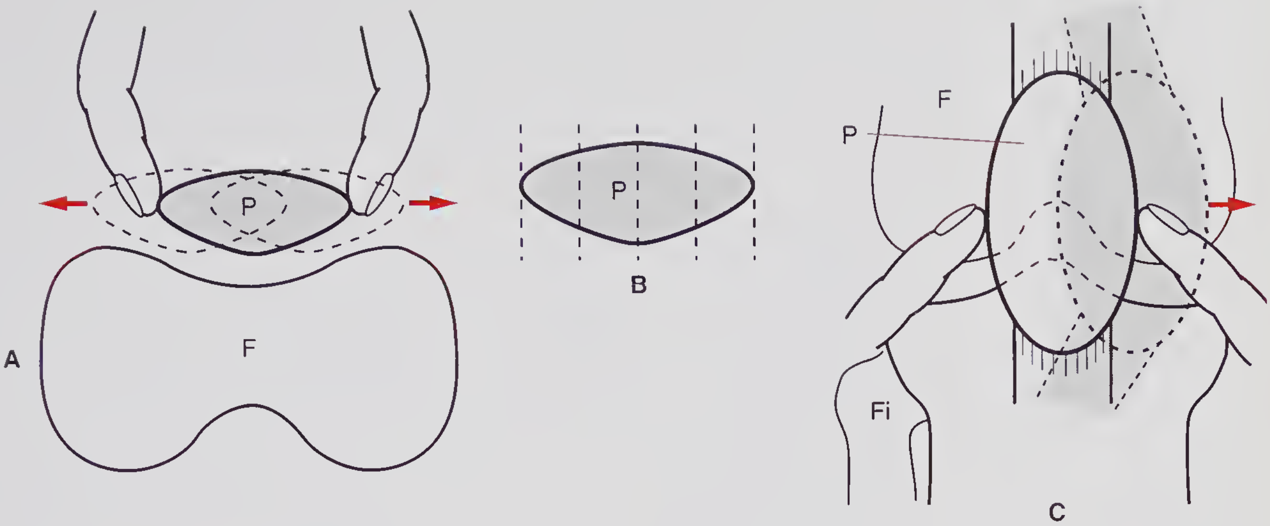


FIGURE 6.45

Testing Lateral Medial-Patellar Movement Lateral-medial passive movement testing is demonstrated as is the expected range of motion. P indicates patella; F, femur; and Fi, fibula.

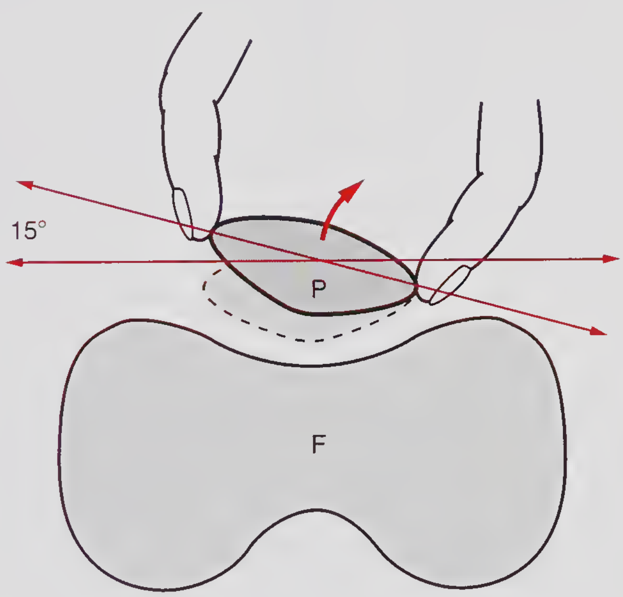


FIGURE 6.46

Testing Patellar Tilting Technique of testing patellar (P) tilting of approximately 15 degrees. F indicates femur.

POSTERIOR THIGH-KNEE MUSCLES

The posterior thigh and lower leg muscles cross over the knee joint posteriorly and both flex the knee and assist in its rotation. The posterior thigh muscles are best divided into medial and lateral groups. The medial group contains the semimembranous and semitendinous muscles, and the main lateral muscle is the biceps femoris (Figure 6.47).

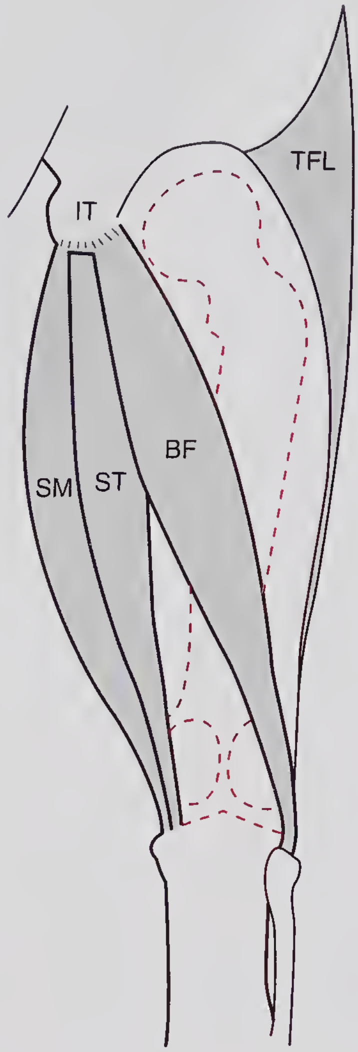


FIGURE 6.47

Posterior Thigh Muscles Posterior thigh muscles acting on knee are the lateral group, semimembranous (SM) and semitendinous (ST), and the medial group, biceps muscle of the thigh (BF). They all originate from ischial tuberosity (IT) of pelvis. Tensor muscle of fascia lata (TFL) originates from iliac crest and passes downward parallel to femur, attaching to lateral aspect of knee to lateral collateral ligament.

The semimembranous muscle originates from the ischial tuberosity of the pelvis, blending with the origin of the long head of the musculus biceps femoris. It descends the medial aspect of the femur, crosses the knee joint, and inserts upon the tibia by a thick tendon that is divided into three branches. The thicker medial branch of the tendon attaches to the popliteus muscle and sends a branch to the medial meniscus (Figure 6.48).

The action of the semimembranous muscle is to flex the knee and, when flexed, to rotate the tibia on the femoral condyles. The semitendinous muscle also originates from the ischial tuberosity and inserts into the medial surface of the tibia in a vertical line immediately posterior to the sites of attachment of the sartorius and gracilis muscles. These 3 muscles—the semitendinous, sartorius, and gracilis—form a conjoined tendon called the pes anserinus (Figure 6.49). A bursa exists under this conjoined tendon.

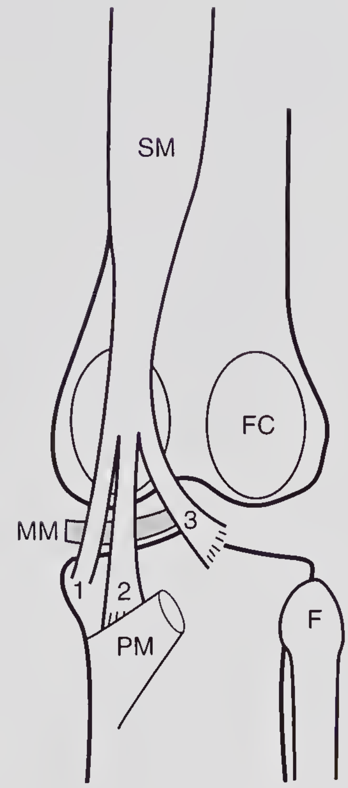


FIGURE 6.48

Insertion of Semimembranous Muscle Semimembranous muscle (SM) passing over medial femoral condyle (FC) ending in 3 tendons: 1 inserts on medial aspect of posterior tibia and medial aspect of medial meniscus (MM); 2 inserts on middle aspect of tibia and onto popliteal muscle (PM); and 3 inserts on mediolateral aspect of tibia and onto lateral aspect of medial meniscus. F indicates fibula.

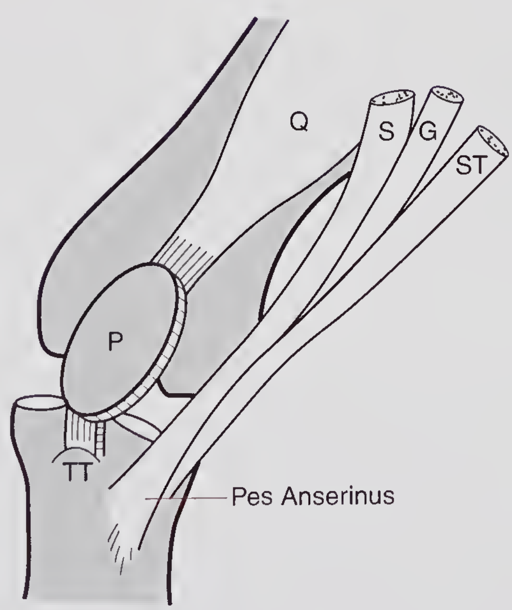


FIGURE 6.49

Pes Anserinus Medial insertion of outer hamstring muscles, semitendinous (ST) muscle, merges with tendons of gracilis (G) and sartorius (S) muscles to form conjoined tendon called pes anserinus. Quadriceps (Q) attaches to patella (P) on tibial tubercle (TT).

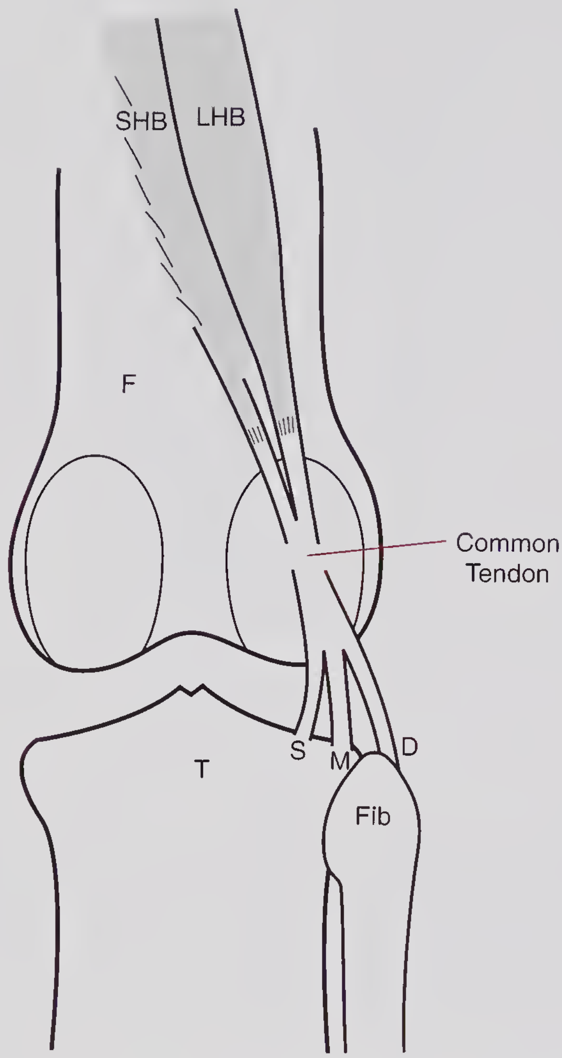


FIGURE 6.50

Biceps Femoris Tendon Long head of biceps femoris muscle (LHB) remains fleshy until about 10 cm above knee joint, where it becomes flat tendon. Short head of biceps femoris (SHB) remains fleshy until it reaches fibular head (FIB). Common tendon of both heads splits into 3 bands: superficial (S), middle (M), and deep (D). F indicates femur; T, tibia.

The lateral flexor of the hamstring group is the biceps femoris muscle. The long head of the biceps femoris originates from the ischial tuberosity and descends posteriorly to the femur, blending midway to the short head of the biceps femoris, which originates from the linea aspera of the femur. All the hamstring muscles except the short head of the biceps cross 2 joints in their course, thus having action on the knee and the hip joint.

The long head of the biceps femoris muscle forms a broad flat tendon 7 to 10 cm above the level of the knee joint, where it is joined by the fleshy end of the deep head. It ultimately divides into 3 tendinous inserts: superficial, middle, and deep layers.

The superficial layer forms 3 expansions: anterior, middle, and posterior. The anterior is thin, albeit resilient, and fans forward and downward into

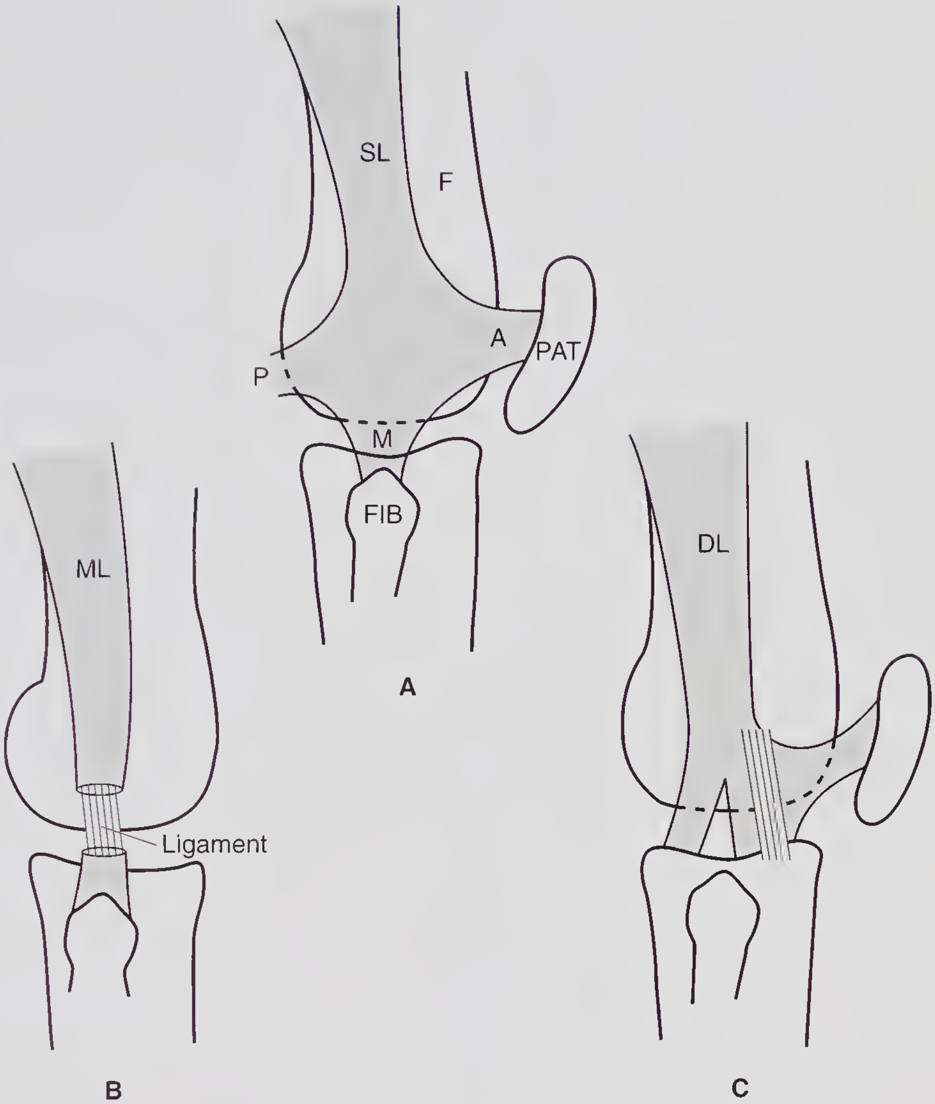


FIGURE 6.51

Layers of Common Biceps Tendon A, Divisions of superficial common biceps tendon (SL) blend with anterior crural fascia, attaching to patellar tendon (PAT). M indicates middle extension to lateral collateral ligament and fibular head (FIB); P, posterior division that attaches to fascia of calf muscles. B, Middle layer (ML) envelops lateral collateral ligament. C, Deep layer (DL) bifurcates into strand of fibular head and into the half passing behind femoral fibular ligament.

the lower leg. The middle layer is also thin and divides to surround the lateral collateral ligament, from which it is separated by a bursa. The posterior expansion is connected to the collateral ligament and to the capsule of the joint by a firm fibrous band.

The deep layer bifurcates into a fibular and tibial ligament, which attaches to the fibular head and the posterior aspect of the joint capsule. Both superficial and deep layers send fibers anteriorly to attach to the infrapatellar tendon that helps guide the direction of the patella (Figures 6.50, 6.51).

The biceps femoris muscle flexes the knee, and when the knee is flexed, it rotates the tibia externally on the femoral condyles. As the knee flexes, the

middle layer, which surrounds the collateral ligament, causes the ligament to become slack. By its attachment to the capsule, it prevents impingement of the capsule between the femur and the tibia. By its attachment to the iliotibial band, it keeps that band taut during motion of the knee.

Nerve Supply

The flexor muscles receive their nerve supply from the sciatic nerve, which divides into the tibial and common peroneal nerves above the knee joint, below the inferior margin of the long head of the biceps. The tibial nerve supplies the semimembranous and semitendinous muscles and the long head of the biceps muscle (Figure 6.52).

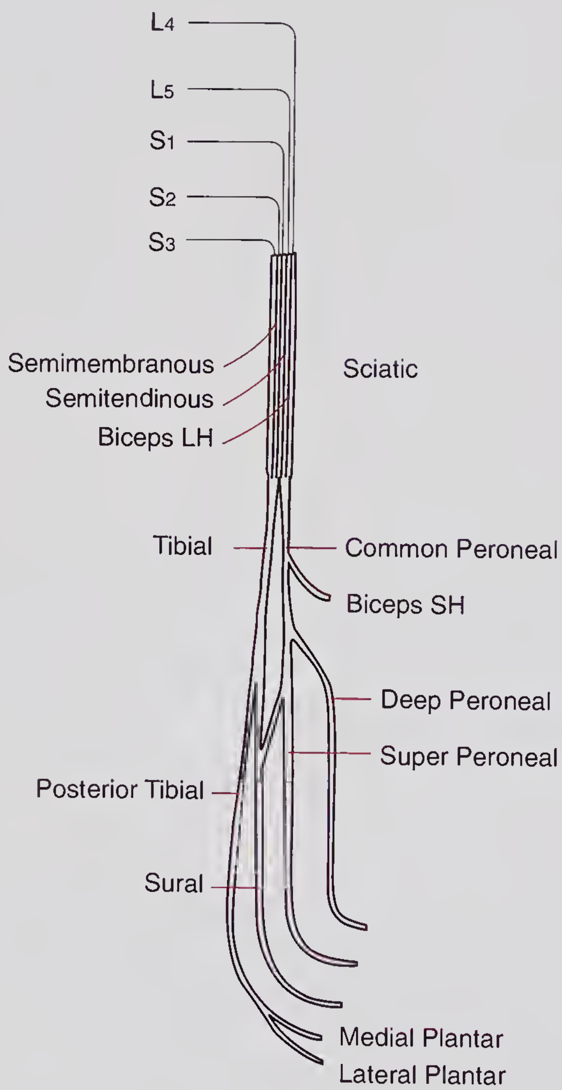


FIGURE 6.52

Nerve Supply of Posterior Muscles of Thigh Sciatic nerve divides into tibial and common peroneal nerves above knee joint and just below inferior margin of long head (LH) of biceps muscle. Common peroneal branch supplies short head (SH) of biceps.

THE KNEE JOINT IN NORMAL GAIT

There are determinants in normal gait that attempt to minimize vertical body displacement to decrease energy expenditure. The trunk shifts from side to side, with simultaneous axial and sagittal rotation, undergoing approximately 2 cm of displacement. The body weight measured from the center of gravity consists of the trunk, head, and upper extremities (Figure 6.53).

The determinants of gait are the swing phase and the stance phase during a normal gait (Figures 6.54, 6.55). During the phase when 1 leg swings, that leg adds 15% weight on the weight-bearing (stance) leg. At the 1-leg stance phase, 85% of total body weight is borne on that leg.

As forward gait begins, the body's center of gravity shifts forward, with the weight remaining on one leg and the other "swinging" forward, essentially to prevent the body falling forward. This is the swing phase, with the hip flexing some 20 degrees and the knee flexing sufficiently for the foot to clear the floor. As the leg clears the swing phase, the forward foot strikes the floor with the heel, as the foot has, at this stage, become dorsiflexed to clear the floor during "swing." As the body passes over the heel-foot stance, the knee goes from the slightly flexed position to full extension so that the body weight is not borne on a flexed knee. At the impact of "heel strike," the knee is slightly bent (15 degrees) to minimize the impact.

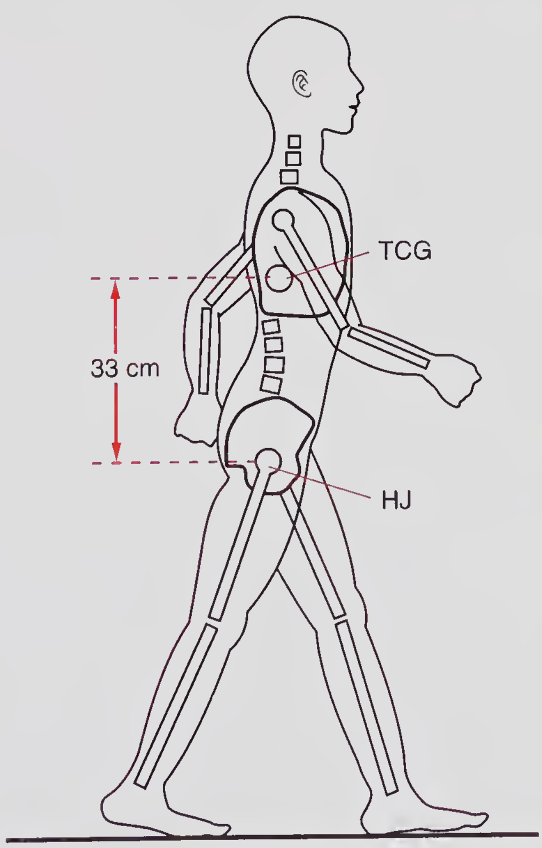


FIGURE 6.53

Center of Body's Gravity Thoracic center of gravity (TCG) is 33 cm above hip joint (HJ) along same center of gravity.

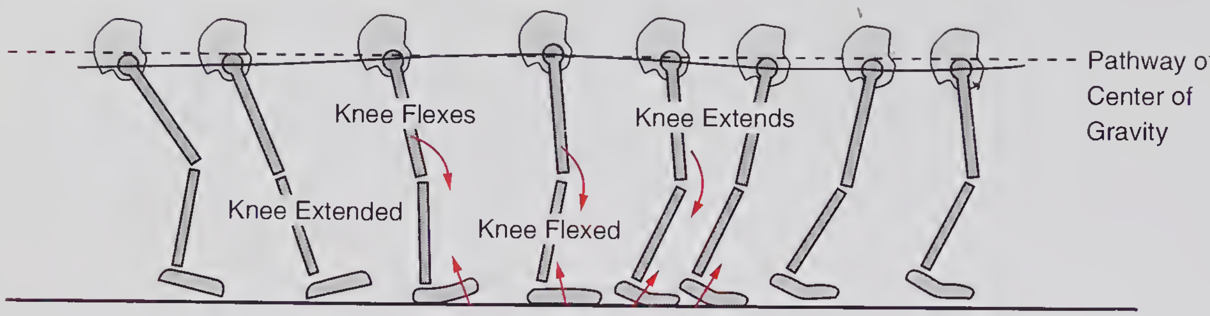


FIGURE 6.54

Knee Flexion-Extension During Gait Knee flexion and extension during gait is portrayed with correlation of center of gravity and heel strike and heel off.

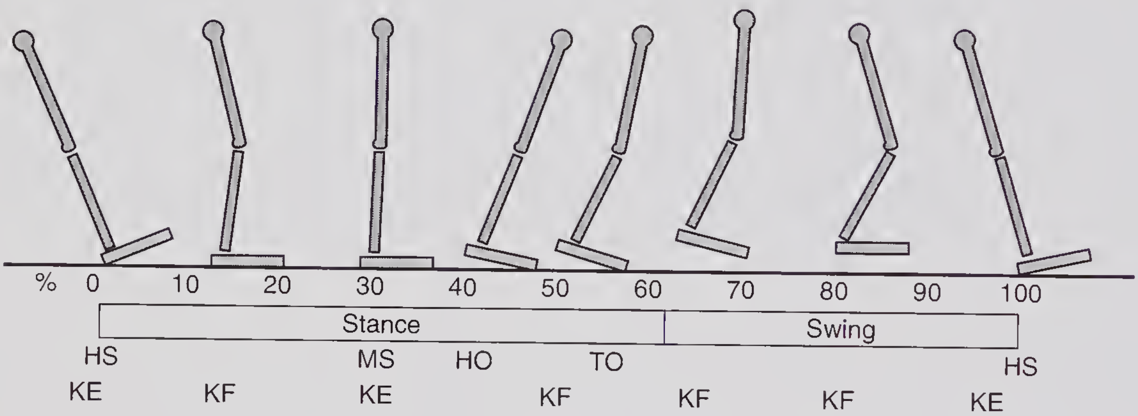


FIGURE 6.55

Gait Cycle Percentage (%) denotes increments of full gait cycle (right leg pictured). HS is heel strike beginning stance phase (0%). At heel strike, knee is extended (KE). As body passes over weight-bearing leg, knee flexes (KF) slightly to absorb shock. At midstance (MS, 30%), knee is fully extended (KE). At heel off (HO, 40%), knee begins to flex slightly (KF, 50%) and remains flexed through toe off (TO, 62%), when swing phase begins. Knee remains flexed throughout swing phase until just before heel strike, when knee reextends (KE, 100%).

After heel impact, the "stance phase" begins as the forward leg now bears the weight. The straightening of the knee occurs not just from contraction of the quadriceps extensor group of muscles but also from the gastrocnemius-soleus group, which attaches above the knee joint, pulling the lower leg back under the knee causing extension.

At midstance, the body passes over the foot at the center of gravity. At this phase, the knee is fully extended, but the extensor mechanism is quiet with no muscular contraction. The knee remains extended until the next swing phase of that limb.

In the determinants of gait, there is some rotation of the pelvis (8 degrees), femur (8 degrees), and tibia (9 degrees), as well as the ankle joint.

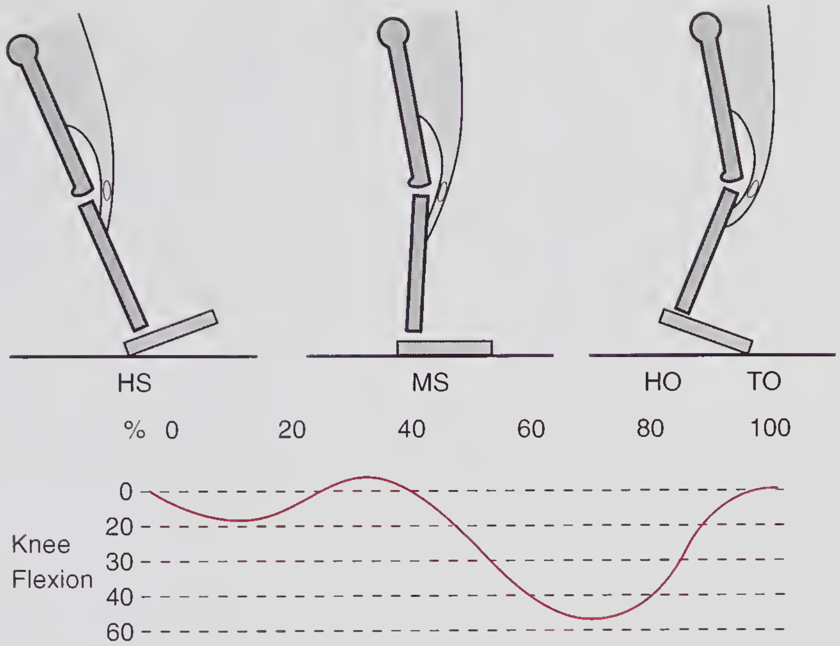


FIGURE 6.56

Knee Flexion and Quadriceps Contraction During Gait At heel strike (HS) at beginning of stance phase (0%), quadriceps is contracted to decelerate as knee flexes. At midstance (MS, 40%) quadriceps actively extends knee. As stance phase progresses, knee again flexes to approximately 60 degrees with quadriceps decelerating further flexion. After toe off (TO, 100%) leg begins swing phase with quadriceps extending knee. HO indicates heel off.

From the onset of the swing phase, all rotation is internal until midphase, when all rotation becomes external until the push-off of the stance foot. Rotation of the femur and tibia is not equal; thus, there is rotation of the tibia on the femur as well as of the femur at the pelvis.

The muscular action initiating these motions is as follows. At initiation of the swing phase, the iliopsoas and the quadriceps muscles contract, as does the short head of the biceps, the gracilis, and the sartorius, which contract to decelerate the swing. The gracilis and sartorius muscles contract to extend the knee and direct it forward.

The quadriceps muscle contracts along with the iliopsoas muscle to initiate the forward swing phase. At heel strike, the quadriceps muscle contracts maximally to absorb the shock, then relaxes to decelerate knee flexion (15 degrees), which decreases the total body elevation during midstance (Figure 6.56).

At the midstance phase, there is slight flexion of the knee, hence, isometric contraction of the quadriceps. After heel strike and the foot becoming firmly planted on the ground, the body passes over the foot with the knee extended but flexing slightly at midphase. The hamstring group of muscles acts as decelerators and probably as kinesthetic proprioceptors (Figure 6.57).

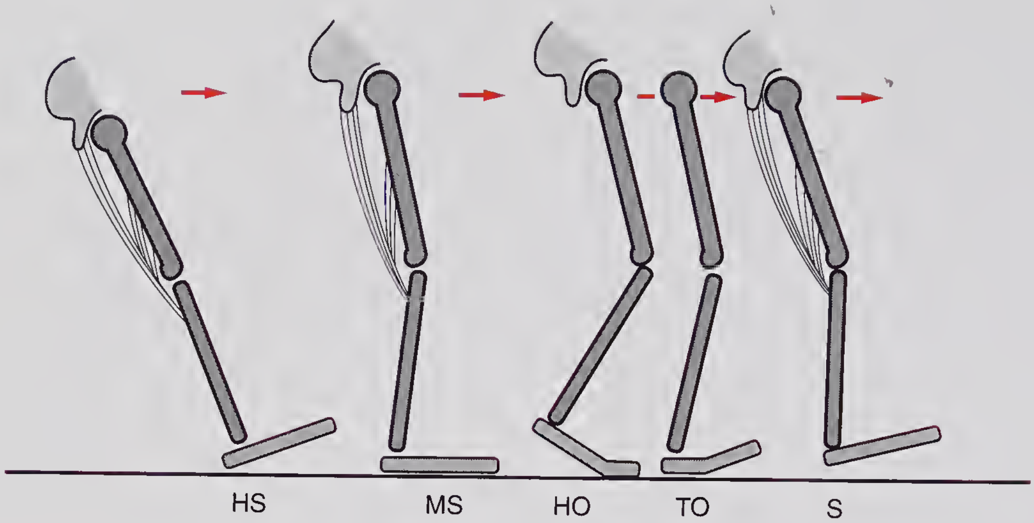


FIGURE 6.57

Hamstring Action in Gait Hamstring muscle group decelerates leg at last phase of swing phase. It assists in extending leg at heel strike (HS). They are pictured in midstance (MS), heel off (HO), toe off (TO), and at heel strike (S).

THE KNEE IN STAIR CLIMBING AND DESCENT

The quadriceps muscle group is vital in stair climbing and descending (Figures 6.58, 6.59).

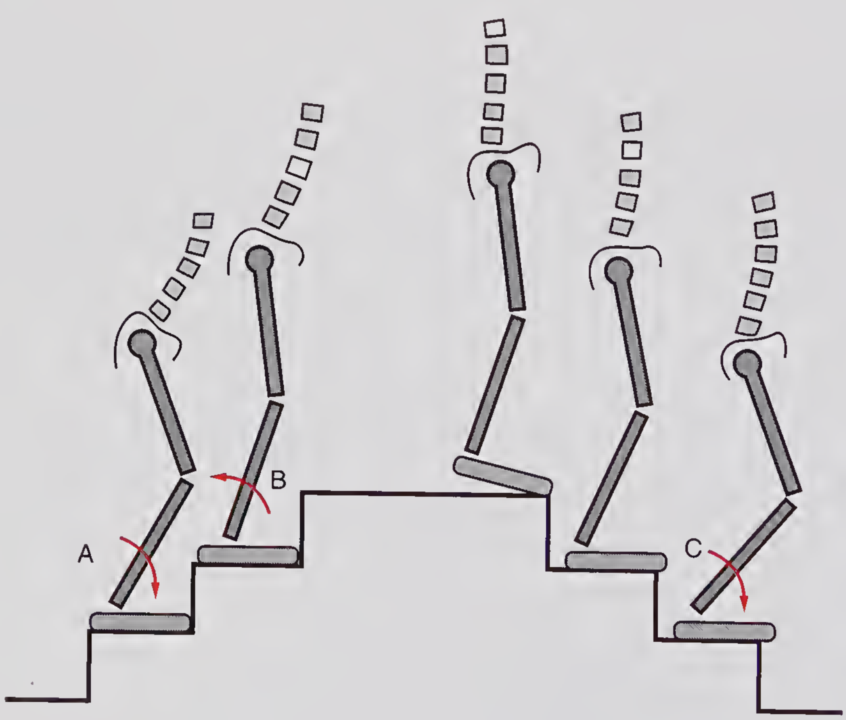


FIGURE 6.58

Stair Climbing and Descent: Joint and Muscle Movements Foot-ankle joint is involved in stair climbing and descending, but quadriceps muscles are major force (A). Foot-ankle joint initially dorsiflexes passively and gradually plantar flexes (B) as knee extends. In descent, quadriceps decelerates descent as foot passively dorsiflexes (C).

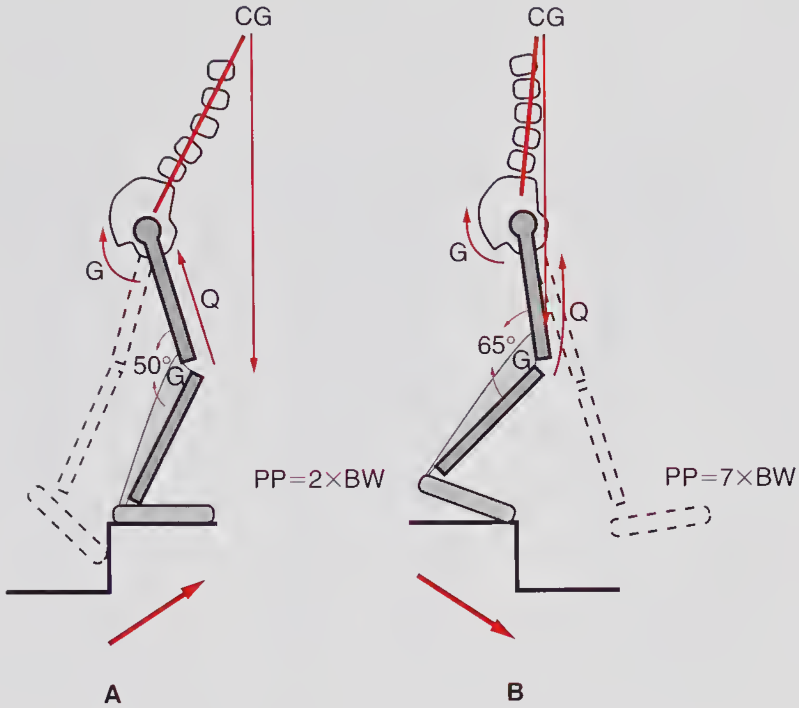


FIGURE 6.59

Stair Climbing and Descent: Patellar Pressure A, In stair climbing, knee flexes 50 degrees as body leans forward, advancing center of gravity (CG) and increasing gluteal efficiency (G). Patellar pressure (PP) occurs due to quadriceps contraction (Q) and is 2 times body weight (BW). B, In stair descent, knee flexes an average of 65 degrees as body returns toward center of gravity. Gluteal efficiency is decreased, and patellar pressure is 7 times body weight.

KNEE DEFORMITIES

There are several terms related to the knee that merit definition: varus, valgus, and recurvatum: *Varus* means "turned inward"; *valgus* "bent outward away from midline"; and *recurvatum* means "bent backward from the midline, viewed from the side" (Figures 6.60, 6.61).

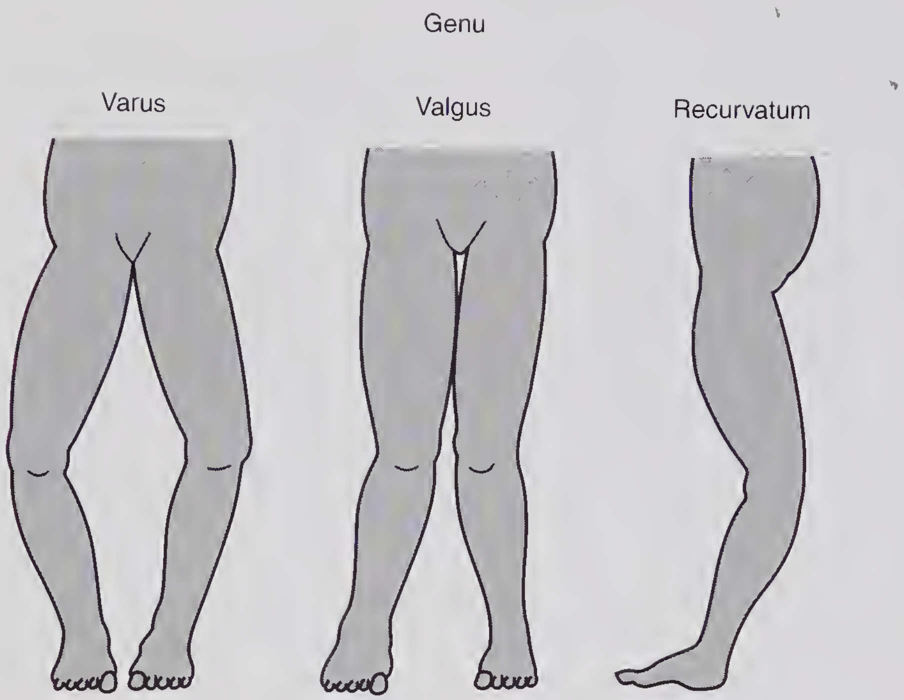


FIGURE 6.60

Varus, Valgus, and Recurvatum of Lower Extremity Lower extremity with knees in varus, valgus, and recurvatum positions.

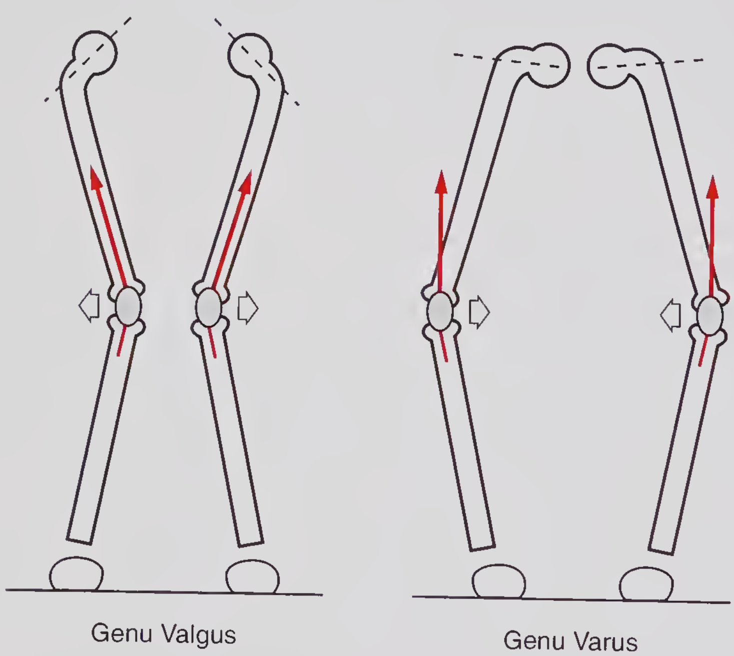


FIGURE 6.61

Effects of Varus and Valgus on Patella Stress on patellar-femoral joints of valgus and varus. Arrows indicate force of quadriceps muscles.

REFERENCES

1. Brantigan OC, Voshell AF. The tibial collateral ligament: its function, its bursae, and its relationship to the medial meniscus. *J Bone Joint Surg*. 1943;25:121.
2. Calliet R. *Knee Pain and Disability*. 3rd ed. Philadelphia, Pa: FA Davis, Co; 1992.

chapter 7

Functional Anatomy of the Hip Joint

The human hip joint is well constructed for its intended use: standing and walking. The hip joint is an outstanding example of a congruous joint. Both the concave (acetabulum) and the convex (femoral head) are symmetrical, and the joint space is equal at all points with slight deviation to permit adequate lubrication. This symmetry allows for rotation about a fixed axis and simplifies the muscle action on that joint.

The weight of the body is superimposed on the fifth lumbar vertebra and then transferred to the base of the sacrum and across the sacroiliac joints to the ilia. When a person is standing, the weight of the body is transferred to the acetabula and finally to the femora. When a person is sitting, the weight is borne on both ischial tuberosities (Figures 7.1, 7.2).

The femoral head articulates within the acetabulum, which is horseshoe-shaped and coated with cartilage around most of its periphery. The center is free of cartilage. The bottom of the "ring" of the peripheral acetabulum is not complete. It is completed as a ring by the transverse acetabular ligament. It is also deepened by a cartilage-covered ring of fibrocartilage termed the *labrum*.

The head of the femur fits into the acetabulum, where it is held firmly by a thick capsule, which is divided into thickened layers forming the iliofemoral, pubofemoral, and ischiofemoral ligaments.

In the standing position, the center of gravity passes behind the center of rotation of the hip joint. The pelvis is angled so that the femoral head is seated directly into the acetabulum. The anterior portion of the capsule is thickened to form the iliofemoral ligament. This permits static stance to exist on ligamentous support without supporting muscular contraction.

In a toe-out stance, the head of the femur is directed in a forward-outward direction. This direction could be one of subluxation except for the support of the iliopsoas muscle tendon rather than from the iliofemoral ligament, which is placed too far laterally for that function.

The head of the femur is coated by a cartilage that acts to cushion compressive forces and lubricates the joint during compression. When not bearing weight, the cartilage imbibes nutritional fluid.

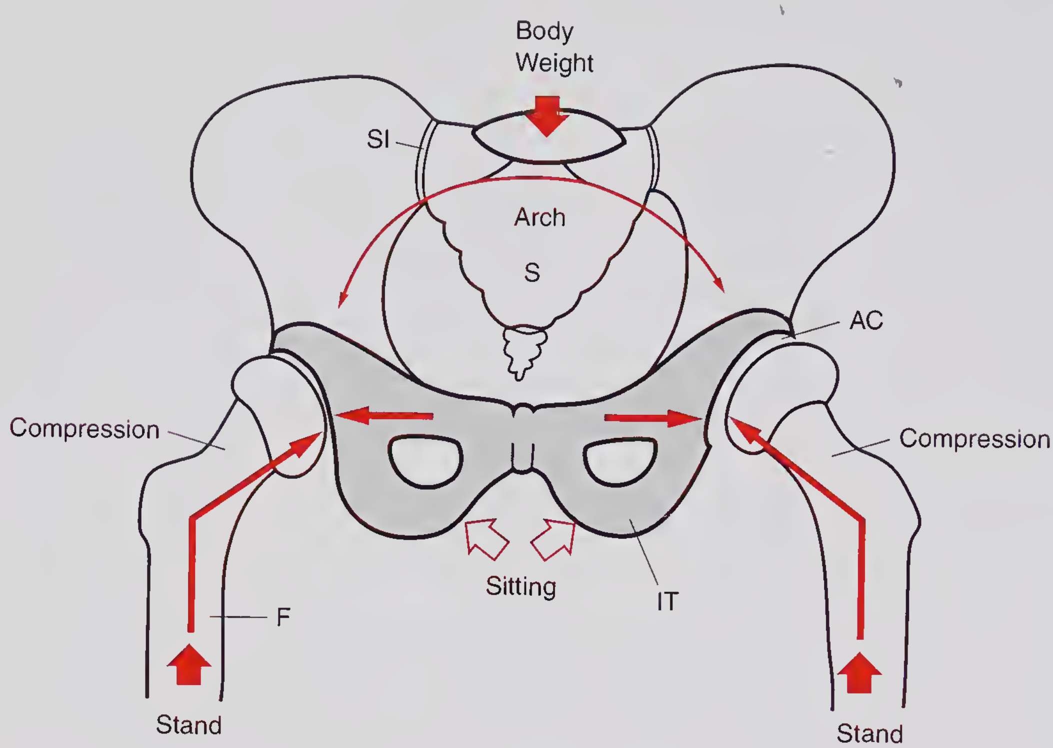


FIGURE 7.1

Weight Bearing of Pelvis Body weight is borne on sacrum (S) and then transmitted through sacroiliac joints (SI), which form an arch. Weight is then taken to acetabular joints (AC). Ilia form pubic struts, which neutralize force on femora (F). Standing causes compression forces at acetabula, and sitting causes compression forces at ischial tuberosities (IT).

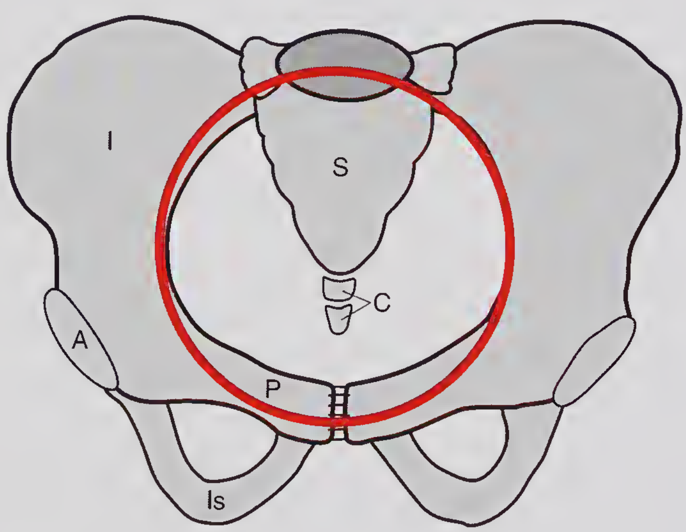


FIGURE 7.2

Pelvic Ring Bony structures of pelvis form ring that contains viscera of pelvis. Components of ring include sacrum (S), ilia (I), pubic bones (P), ischia (Is), and acetabula (A).

There are several angles of the head and neck of the femur that merit review. The head and neck of the femur, when viewed from the front, are at an angle of inclination (Figure 7.3). Viewed from above, the femoral head and neck form an angle of anteversion (Figure 7.4).

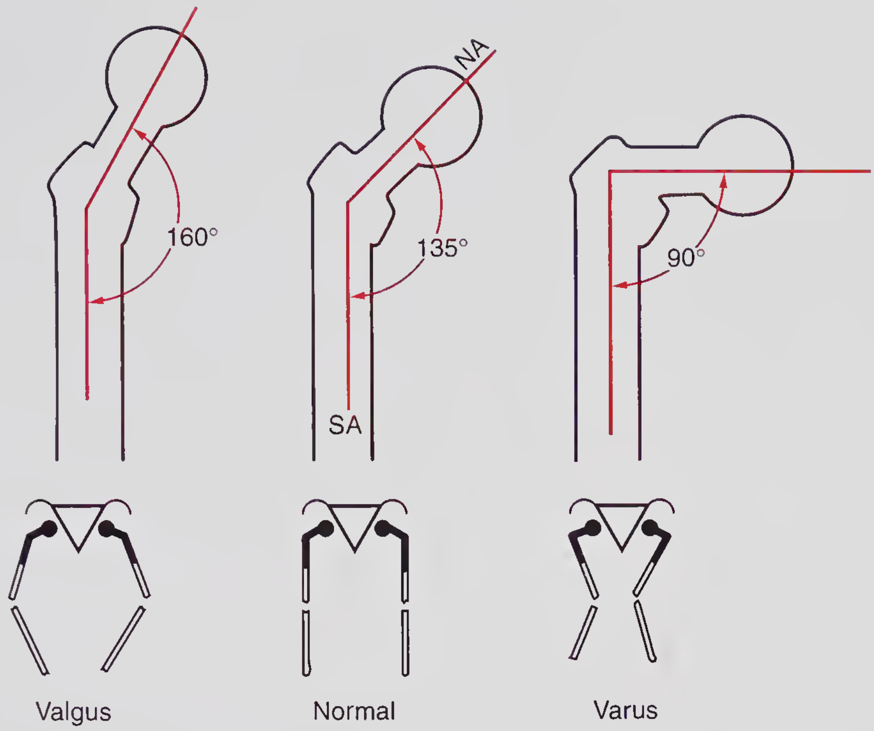


FIGURE 7.3

Angle of Inclination Angle formed by intersecting femoral neck angle (NA) with axis drawn through shaft of femur (SA), which is termed angle of inclination. This angle normally varies between 90 degrees and 160 degrees, with an average of 135 degrees.

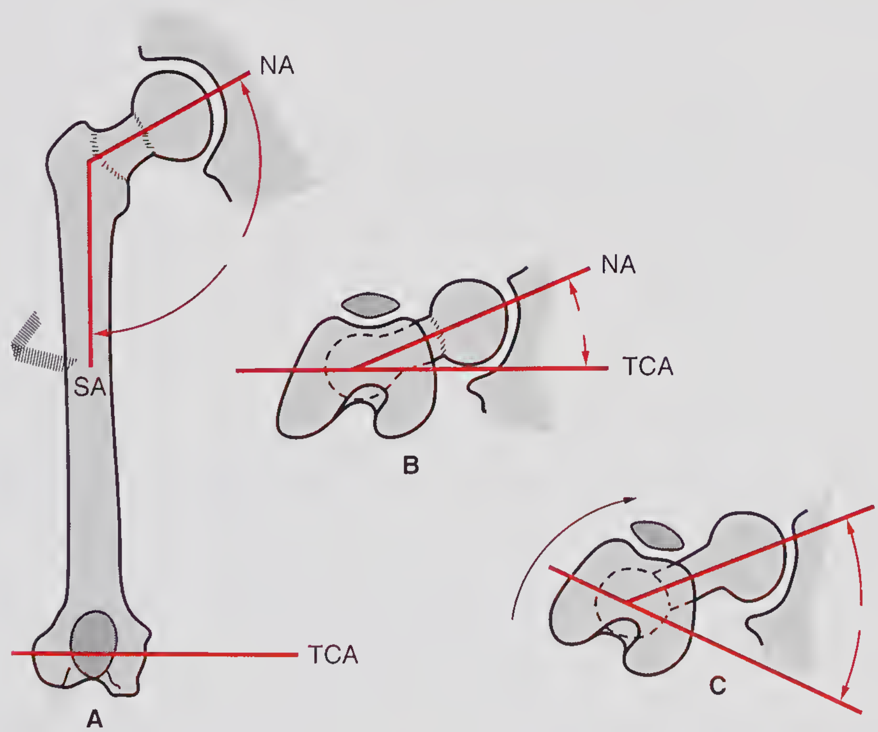


FIGURE 7.4

Angle of Anteversion A, Transcondylar axis (TCA) is transverse line passing through femoral condyles. Axis placed through femoral neck (NA) forms angle with TCA termed *angle of anteversion.* B, Angle femoral head, viewed from above. Angle of 15 to 25 degrees is considered normal. C, Change in angle of anteversion from internal rotation of leg.

HIP RANGE OF MOTION

The ranges of motion of the hip joint include flexion, extension, abduction, adduction, and rotation, with specific physiological limitation by the soft tissues of the joint (Figures 7.5, 7.6).

Flexion is limited by the hamstring muscle group. Extension is limited by the ligamentous thickening of the capsule; abduction, by the adductor group of muscles; adduction, by the tensor muscle and fascia of the abductor muscles; and rotation, by the fibrous capsular fibers (Figure 7.7).

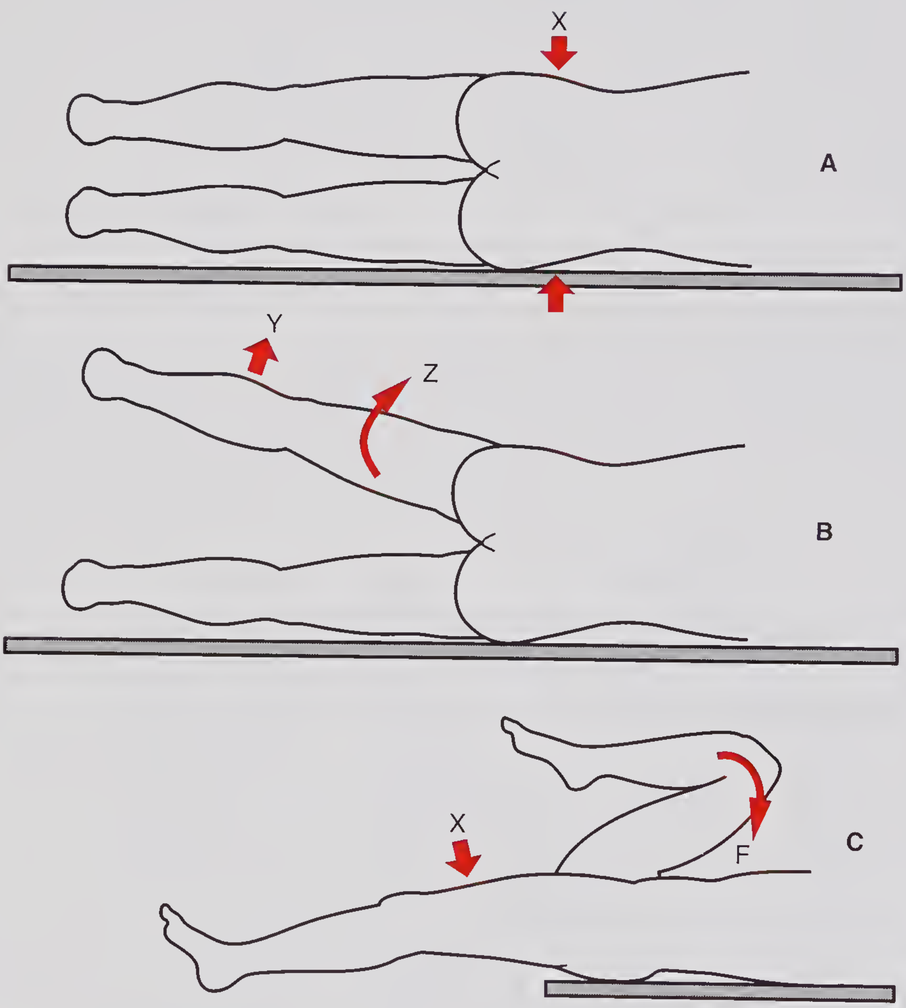


FIGURE 7.5

Hip Range of Motion: Flexion and Extension A, Person lying on side with upper leg in neutral position (X). B, Abduction of leg (Y) and rotation of thigh (Z). C, Hip flexion of right leg (F) and neutral extended position of lower leg (X).

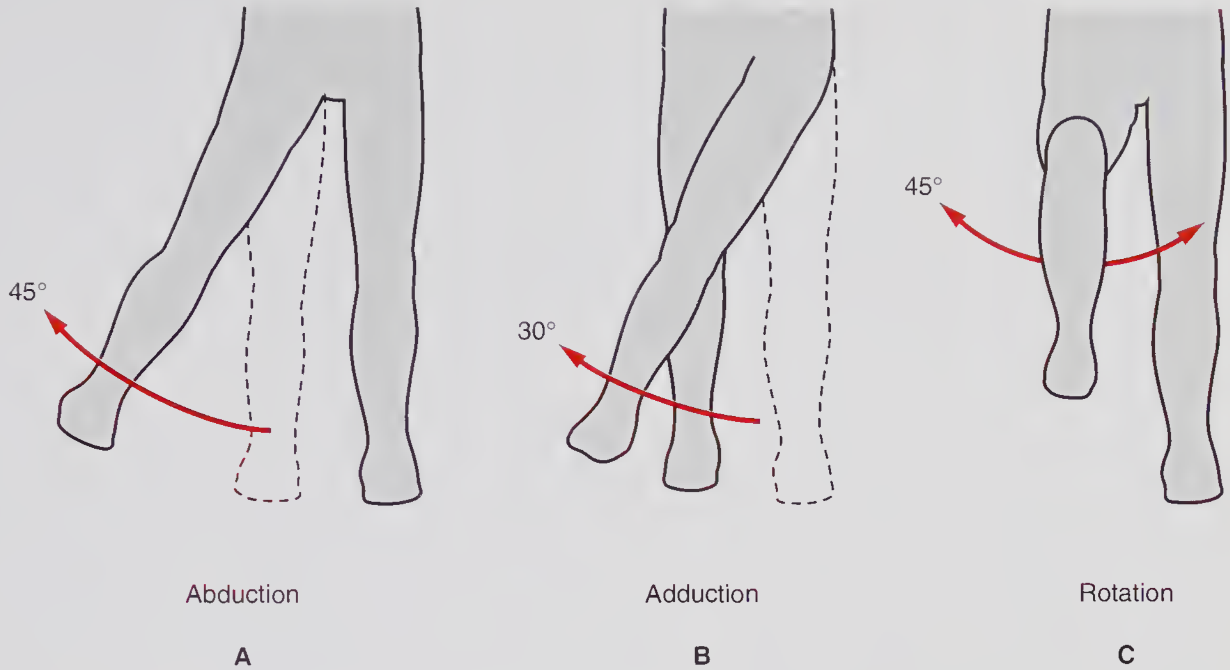


FIGURE 7.6

Hip Range of Motion: Abduction, Adduction, and Rotation A, Abduction (45 degrees). B, Adduction (30 degrees) of hip. C, View from above of rotation (45 degrees) of thigh.

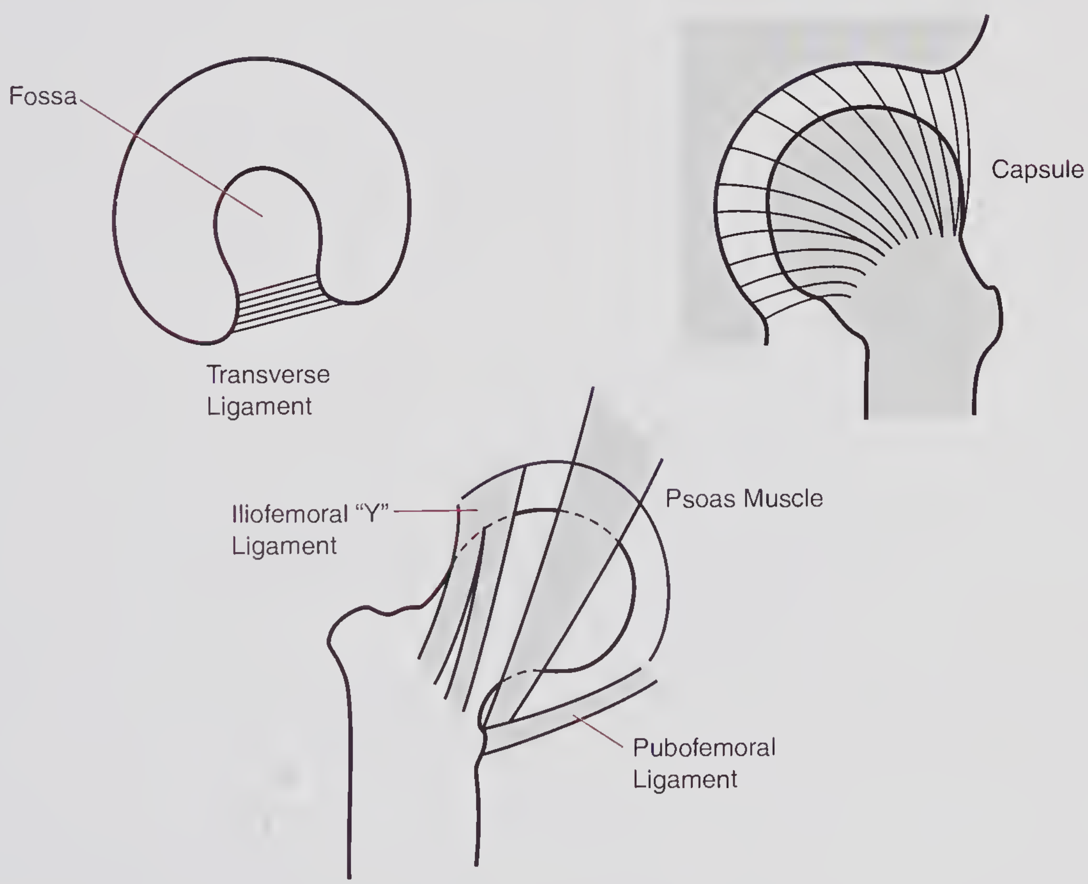


FIGURE 7.7

Rotational Limitation by Capsule Because hip joint is congruous, rotation occurs in all directions. Capsule is relatively slack in neutral position, but fibers tighten during rotation.

MUSCLES OF THE HIP JOINT

Numerous muscles move the hip joint, either directly or indirectly.

Gluteus Maximus

The gluteus maximus is a very course, rhomboidal-shaped muscle that originates from the posterior gluteal line of the os ilium, the tendon of the sacrospinalis, the dorsal surface of the sacrum, the coccyx, and the sacrotuberous ligament. It inserts on the greater tuberosity of the femur and the iliotibial tract of the fascia lata lateral to the femur.

Its action is to extend the hip, and it assists in externally rotating the hip. In the standing position when the leg is fixed on the ground, this muscle extends the pelvis on the upper leg. Its nerve supply is the inferior gluteal nerve (Figure 7.8).

The piriform muscle originates from the anterior surface of the sacrum, the capsule of the sacroiliac articulation, and the margin of the greater sciatic foramen. It inserts on the superior border of the greater trochanter of the femur. Its action is to rotate the femur laterally and to abduct the thigh when the leg is flexed. Its nerve supply is the sacral plexus (L5, S1, and S2).

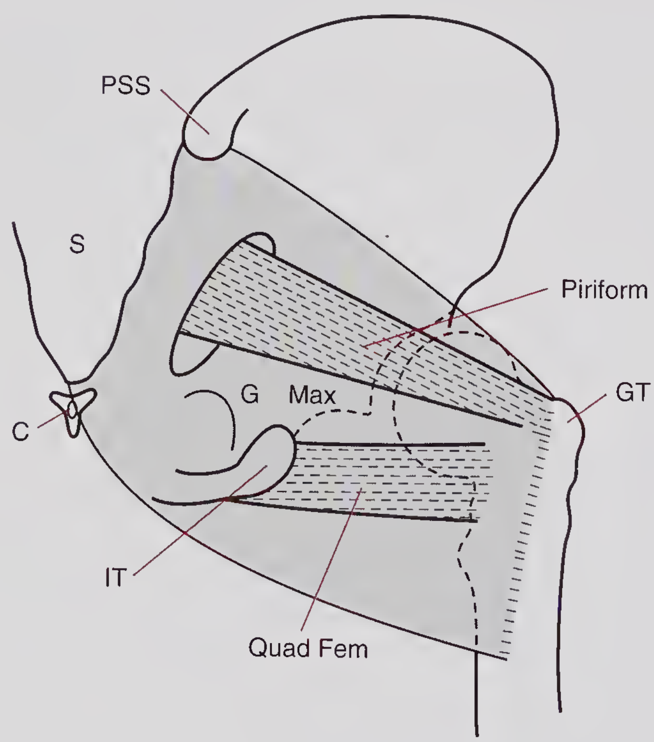


FIGURE 7.8

Gluteus Maximus Gluteus maximus muscle (G Max) overlies the piriform and the quadratus femoris muscles (Quad Fem). Sites of origin and attachment are posterior superior spine (PSS) of os ilium, sacrum (S), coccyx (C), and greater tuberosity of femur (GT) from roots L4, L5, S1, and S2.

Gluteus Medius and Minimus

The gluteus medius and minimus are essentially 2 parts of the same muscle; their anterior borders are fused. Their origin is the outer surface of the os ilium from the iliac crest and the posterior gluteal line above to the anterior gluteal line below and the gluteal aponeurosis. It inserts on the lateral surface of the greater trochanter of the femur. Its action is to abduct the thigh and rotate it medially (inward). Its nerve supply is the superior gluteal (L4, L5, and S1) (Figure 7.9).

Iliopsoas Muscles

The psoas muscle originates from the anterior surface of the transverse processes and lateral borders of the lumbar vertebrae from T12 through L5. It inserts on the lesser trochanter of the femur with a conjoined tendon of the iliac muscle. Its action is primarily to flex the thigh and give minimal action of lateral rotation (external) and abduction. Its nerve supply is the lumbar plexus (L1, L2, L3, and L4).

The iliac muscle originates from the upper two thirds of the iliac crest; inner border of the iliac crest; anterior sacroiliac, lumbosacral, and iliolumbar ligaments; and the ala of the sacrum. It inserts as a conjoined tendon with the psoas muscle on the lesser trochanter of the femur. Its nerve supply is the femoral nerve (L1, L2, and L3) (Figure 7.10).

Hamstring Muscles

The hamstring medial group of muscles includes the semitendinous and semimembranous muscles. These muscles originate from the ischial tuberosity along with the biceps femoris muscle. They insert on the proximal portion

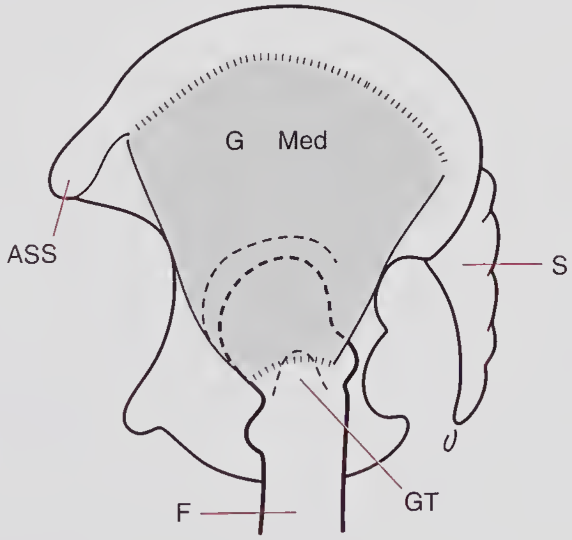


FIGURE 7.9

Gluteus Medius Minimus Gluteus medius and minimus (G Med) originates from outer surface of os ilium (ASS, anterior superior spine) and sacrum (S). It attaches to greater trochanter (GT) of femur (F).

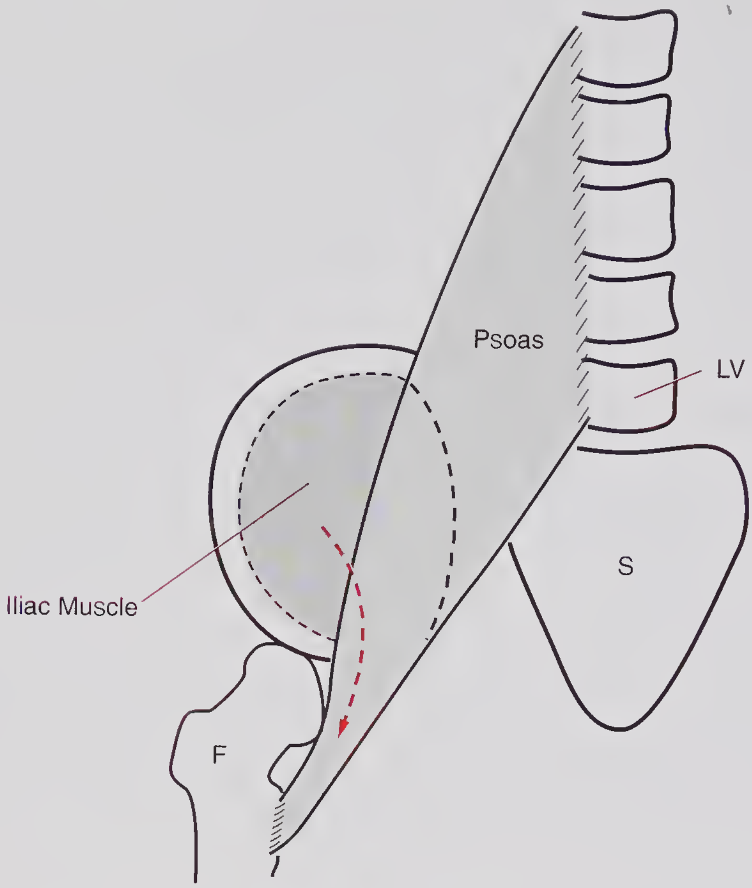


FIGURE 7.10

Iliopsoas Muscles Psoas muscle (shown superficial to iliac muscle) originates from lumbar vertebrae (LV) L1 through L5 and inserts on lesser trochanter of femur (F). Iliac muscle (under psoas) originates from crest of os ilium. It inserts (curved dotted arrow) as a conjoined tendon to lesser trochanter of femur (F). S indicates sacrum.

of the tibia and deep fascia of the leg. Their action is to flex the knee and simultaneously internally rotate the lower leg as well as to adduct and extend the leg. The semimembranous muscle originates from the upper and lateral aspect of the ischial tuberosity and inserts on the posteromedial surface of the medial condyle of the tibia.

The long head of the biceps femoris muscle originates from the ischial tuberosity and sacrotuberous ligament, and the short head originates from the lateral aspect of the linea aspera and the lateral supracondyle of the femur. It inserts on the lateral aspect of the head of the fibula, lateral condyle of the tibia, and deep fascia. Its action is primarily to flex the knee, laterally rotate the lower leg on the femur, and slightly adduct the leg. Its nerve supply is the long head from the sciatic nerve's tibial branch (L5, S1, S2, and S3) and the short head from the peroneal branch of the sciatic nerve (L5, S1, and S2) (Figure 7.11).

Tensor Muscle of Fascia Lata

The tensor muscle of fascia lata originates from the anterior part of the outer lip of the iliac crest and the anterior border of the os ilium. It attaches to the middle one third of the iliotibial tract of the fascia lata. Its action is

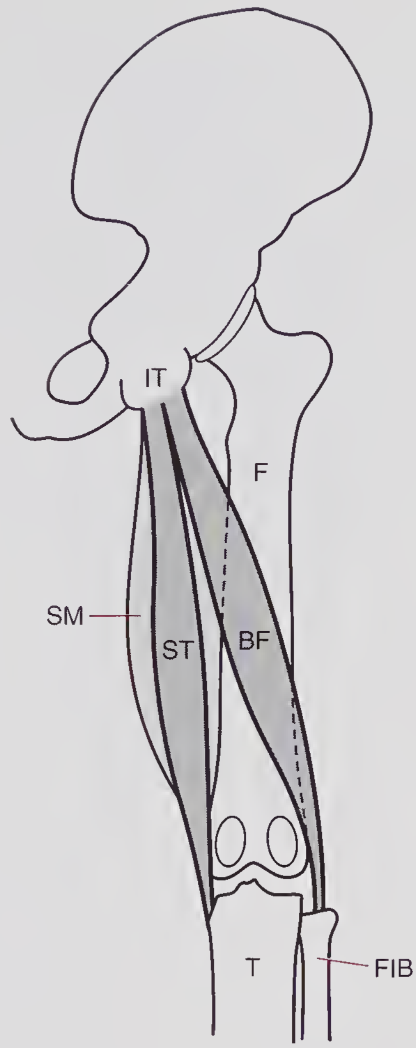


FIGURE 7.11

Hamstring Muscle Group Hamstring muscle group includes semimembranous (SM), semitendinous (ST), and biceps femoris (BF) muscles. IT indicates ischial tuberosity; F, femur; T, tibia; and FIB, fibula.

thigh flexion, abduction, and medial rotation. It tenses the fascia lata and laterally stabilizes the knee joint. Its nerve supply is the superior gluteal nerve (L4, L5, and S1) (Figure 7.12).

There are numerous adductors of the leg, including the musculi pectineus, adductor brevis, adductor longus, and gracilis. The musculus pectineus originates from the superior surface of the pubis between the iliopectineal eminence and the pubic tubercle. It inserts on the pectineal line from the lesser trochanter to the linea aspera. The musculi adductor longus and brevis originate from the outer surface of the inner ramus of the pubis and insert on a line extending from the lesser trochanter to the linea aspera. The musculus adductor magnus originates from the ischial tuberosity, the ramus of the ischium, and the pubis. It inserts on a line extending from the greater trochanter along the linea aspera extending to the adductor tubercle of the medial condyle of the femur. The musculus gracilis originates from the lower one half of the symphysis pubis and

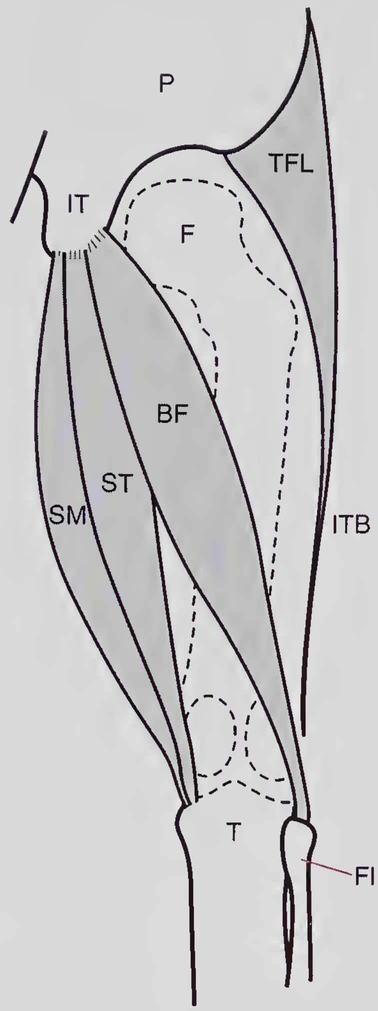


FIGURE 7.12

Hamstring Group and Tensor Fascia Lata Adductors Posterior thigh muscles—semimembranous (SM), semitendinous (ST), biceps femoris (BF), and tensor fascia lata (TFL) attaching to iliotibial band (ITB). IT indicates ischial tuberosity; P, pelvis; F, femur; T, tibia; FI, fibula.

medial margin of the inferior ramus of the pubic arch. It inserts on the upper part of the medial surface of the tibia distal to the condyle. Its action is to adduct the thigh and flex the hip and knee as well as to medially rotate the thigh and tibia. Its nerve supply is the obturator nerve (L2, L3, and L4) (Figure 7.13).

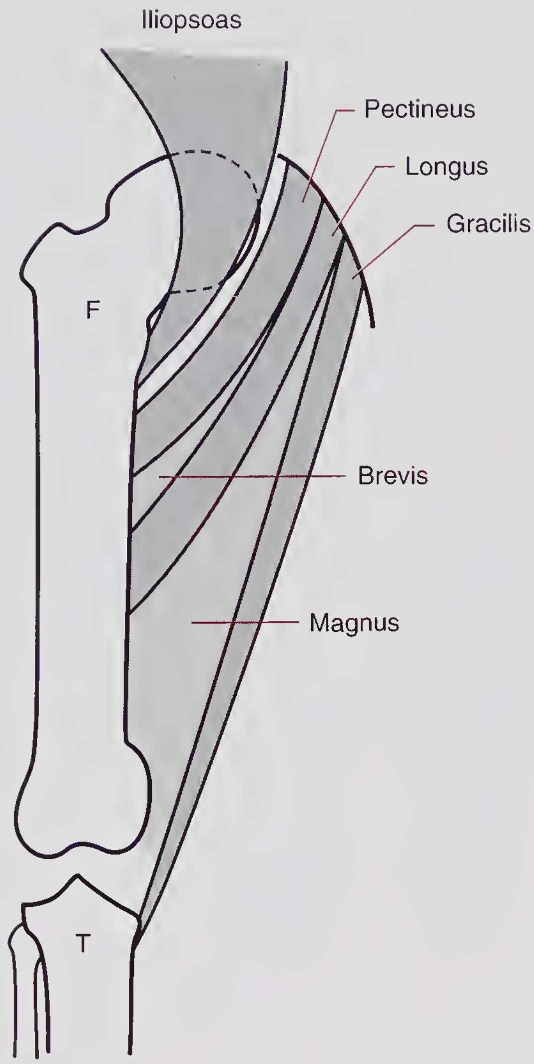


FIGURE 7.13

Adductor Muscle Group of Thigh Adductor muscles of thigh. F indicates femur; T, tibia.

Sartorius Muscle

The sartorius muscle, so named because historically it pertains to a tailor sitting squat to sew, originates from the anterior superior iliac crest and upper half of the iliac notch. It crosses the upper leg and inserts on the upper part of the medial surface of the tibia near its anterior border. Its action is to flex the knee and hip, rotate the thigh laterally, and, when the knee is flexed, rotate the tibia medially. Its nerve supply is the femoral nerve (L2 and L3) (Figure 7.14).

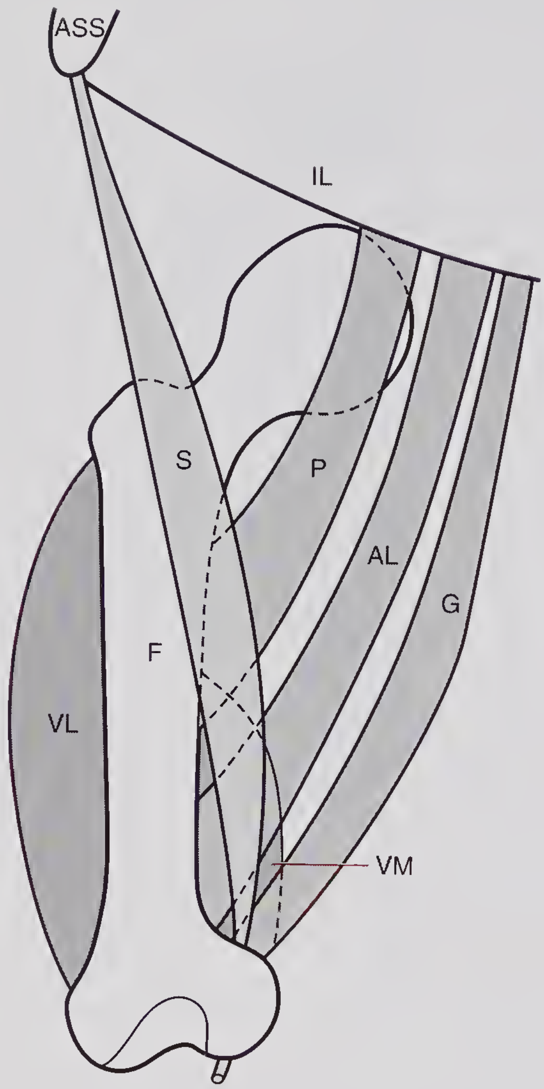


FIGURE 7.14

Sartorius Muscle Sartorius muscle (S) is anterior thigh muscle acting on both femur (F) and tibia. It originates from anterior superior spine (ASS). IL indicates inguinal ligament; VL, vastus lateralis of quadriceps muscle group; P, musculus pectineus; AL, musculus adductor longus; G, musculus gracilis; and VM, vastus medius of quadriceps group.

FEMORAL TRIANGLE

The femoral triangle (triangle of Scarpa) is a triangular trough through which pass the deep femoral artery, the circumflex branches, and the deep femoral vein and nerve. The triangle has its base formed by the inguinal ligament and its apex approximately 10 cm below where the sartorius muscle crosses the lateral border of the musculus adductor longus (Figure 7.15).

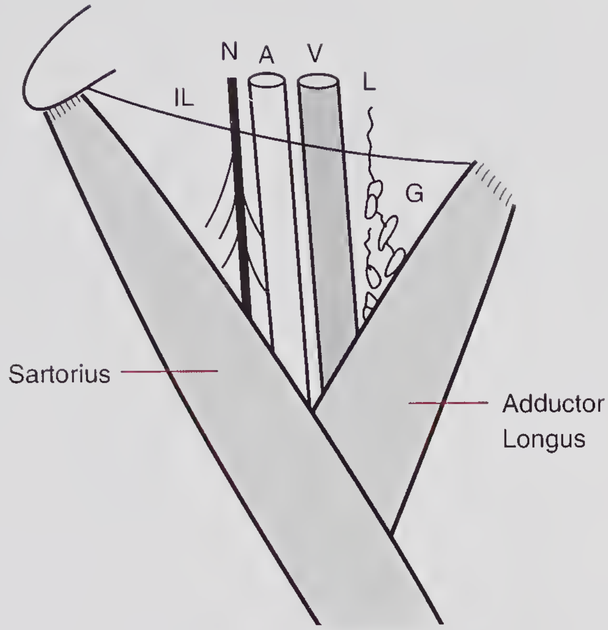


FIGURE 7.15

Femoral Triangle Contents of femoral triangle are femoral artery (A), vein (V), and nerve (N); branches of nerve; and numerous lymph glands (G). IL indicates inguinal ligament; L, lymphatics.

THE HIP IN GAIT

In the determinants of gait, the femur rotates internally on the pelvis (5 degrees) and the tibia rotates on the femur as it moves from stance to swing phase. Then the femur rotates externally about 7 degrees during the remainder of the stance and early swing phases. The hip flexes during the swing phase, becomes neutral during midstance phase, and then extends as the other leg goes through the swing phase (Figure 7.16).

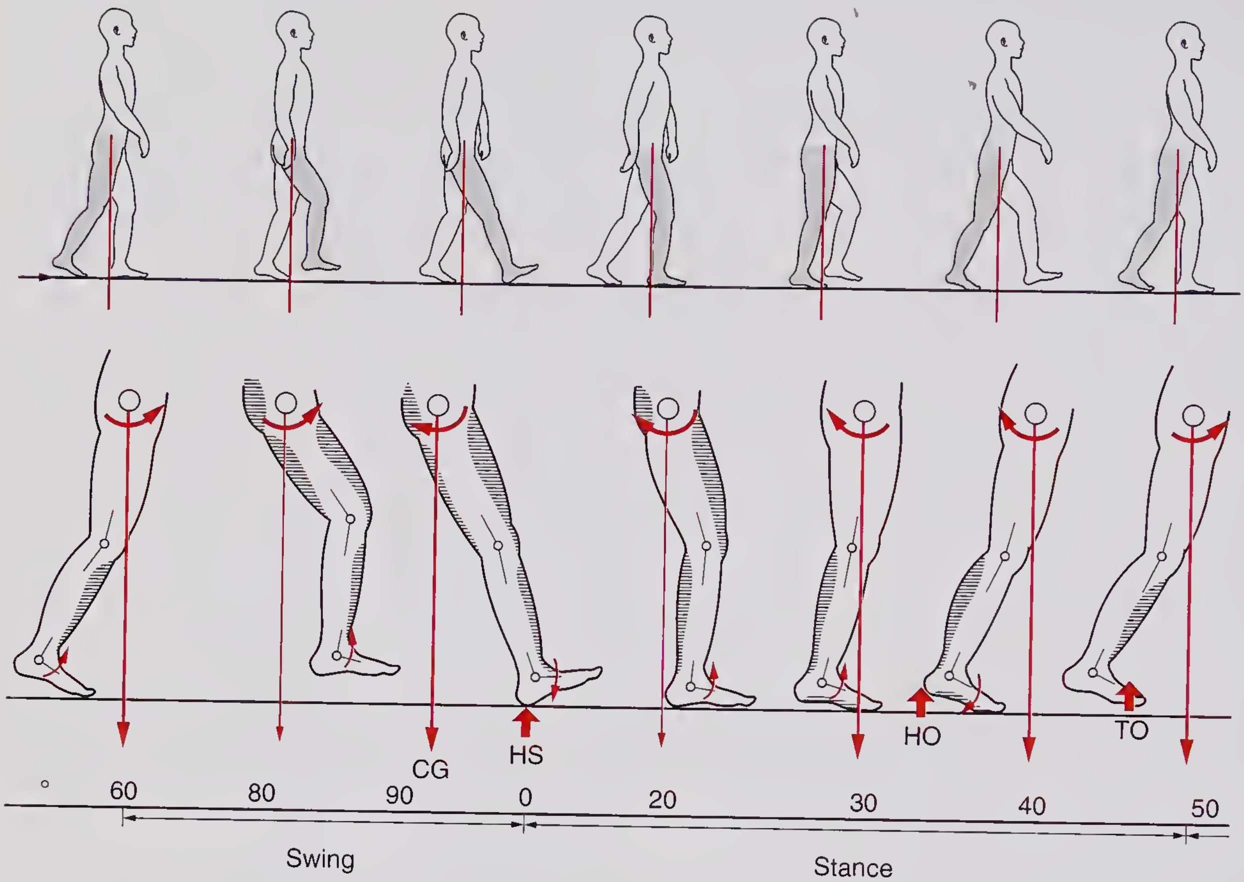


FIGURE 7.16

Hip During Normal Gait Curved arrows depict flexion-extension of hip during normal gait. Hip initially swings 60 degrees of swing phase until heel strike (HS), when hip begins extension until heel off (HO) and toe off (TO). CG indicates center of gravity.

chapter 8

Functional Anatomy of the Foot and Ankle

The ankle is the articulation between the talus bone of the foot and the mortise between the distal tibia and fibula. The tibia and the fibula are connected with an oblique interosseous membrane that permits separation of a limited degree when the varying widths of the talus mechanically separate the 2 bones to widen the mortise. The fibers of the interosseous membrane do not elongate but merely change their angulation, which permits separation of the tibia and fibula (Figures 8.1, 8.2).

The interosseous ligament can rightfully be called the tibiofibular ligament, with its fibers attached along a linear line on the lateral aspect of the tibia and the medial aspect of the fibula (Figure 8.3).

THE ANKLE JOINT

The ankle joint is the talus of the foot between the malleolus of the tibia medially and the malleolus of the fibula laterally. This joint is unstable and is made more stable by the medial and lateral ligaments (Figures 8.4, 8.5, 8.6).

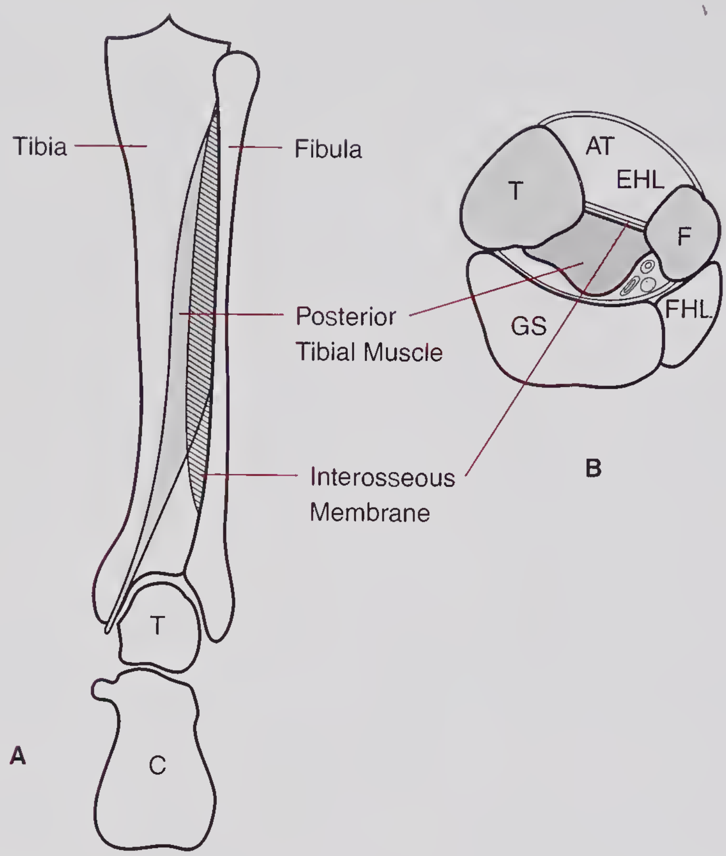


FIGURE 8.1

Rear View of Lower Aspect of Leg A, Lower aspect of leg, with tibia (T) and fibula (F) forming ankle mortise containing talus (T) of foot. Tibia and fibula are connected by interosseous membrane. B, Cross section of lower aspect of leg. GS indicates gastrocnemius and soleus muscles; AT, anterior tibial muscle; EHL, long extensor muscle of great toe (extensor hallucis longus); FHL, long extensor muscle of great toe (flexor hallucis longus); and C, calcaneus.

The medial collateral ligaments have an eccentric axis of rotation, so that all fibers are taut in the neutral position but the posterior fibers are slack on plantar flexion and the anterior fibers are slack on dorsiflexion. The lateral collateral ligaments have a central axis of rotation, and thus all fibers remain taut during plantar and dorsiflexion (Figure 8.7).

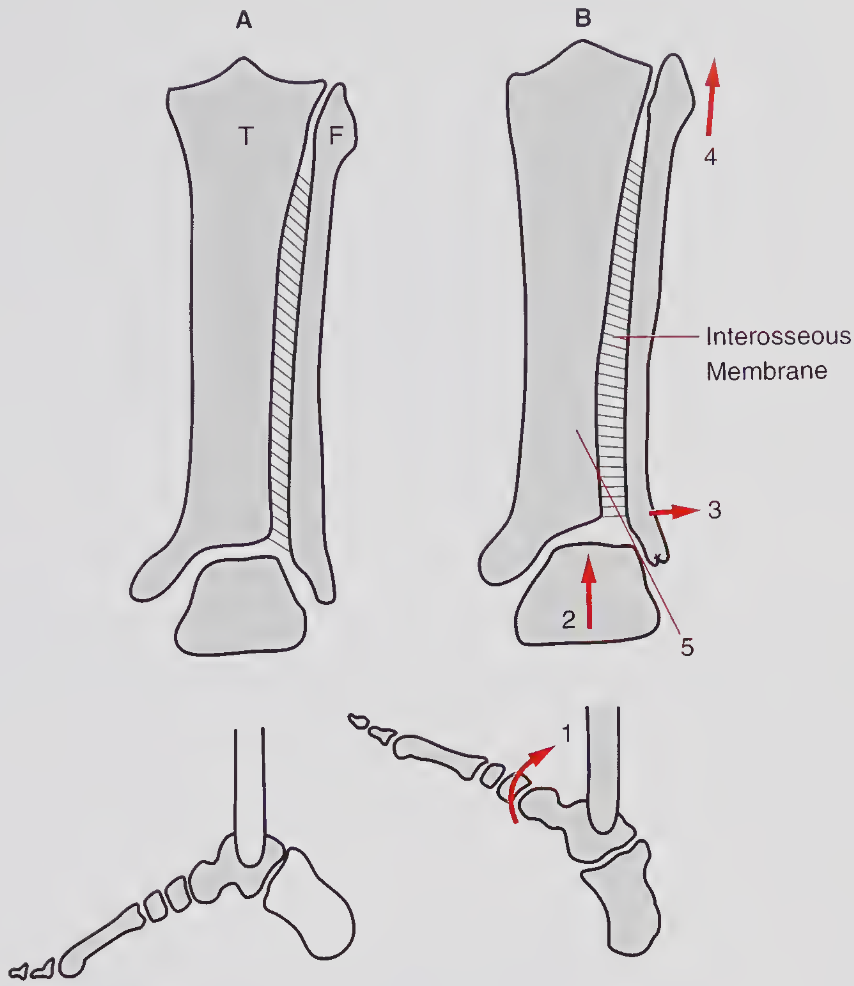


FIGURE 8.2

Effect of Dorsiflexion of Foot on Interosseous Membrane A, With foot in neutral position, fibers of interosseous membrane are oblique and tibia and fibula are reasonably close. B, With dorsiflexion of foot (1), anterior wider portion of talus (2) separates malleoli and straightens direction of fibers of interosseous membrane, allowing separation of 2 bones (3) and rising of fibula (4). Tibia remains weight-bearing on talus (5).

The ligaments run from the malleoli to the talus, calcaneus, and navicular bone. They are well supplied by sensory nerves, which subserve proprioception and mediate pain when damaged.

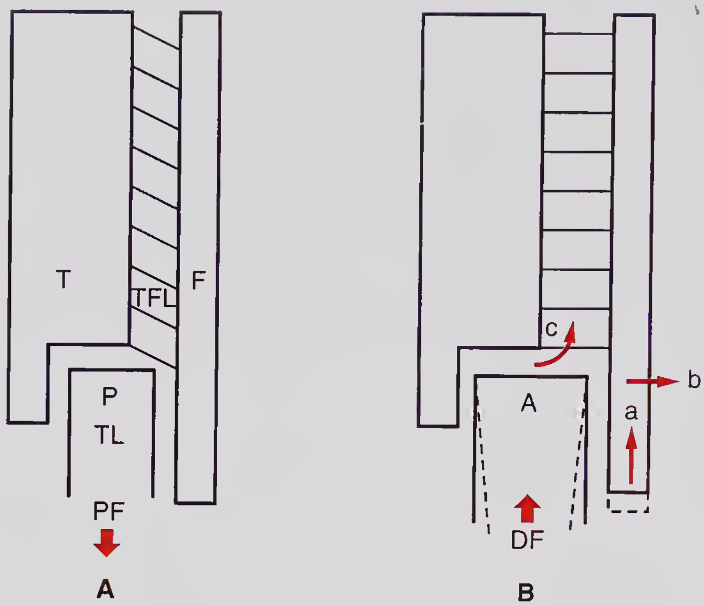


FIGURE 8.3

Tibial-Fibular Ligament A, Schematically, angulation of interosseous ligament fibers (TFL) with foot in plantar flexed position (PF). In this position, talus (TL) has its narrow posterior aspect (P) between tibial (T) and fibular (F) malleoli, and fibers are oblique. B, In dorsiflexed position of foot (DF), anterior wider aspect (A) of talus is between malleoli, and fibers are now horizontal (arrow c); fibula migrates laterally (arrow b) and arises (arrow a).

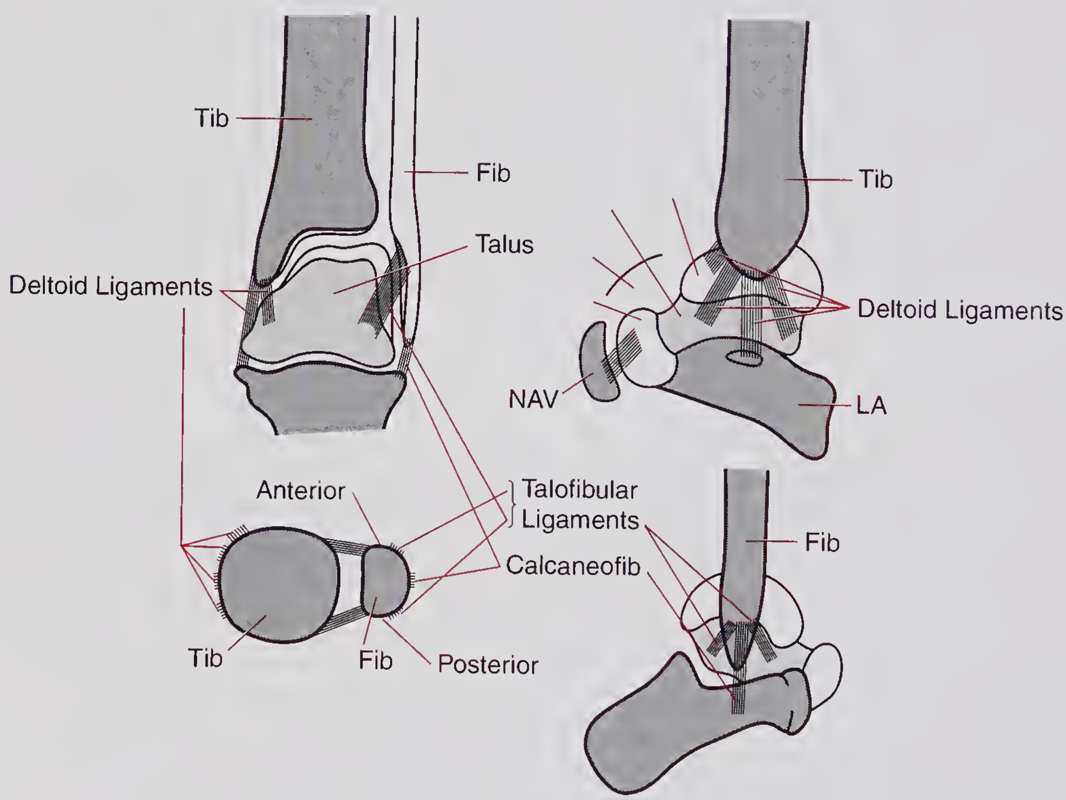


FIGURE 8.4

Collateral Ligaments of Ankle Joint Ligaments of ankle joint unite tibia (Tib) and fibula (Fib) to talus and calcaneus (CA) of foot. Ligaments are termed according to their sites of attachment to navicular bone (NAV) and calcaneus. Upper left figure is rear view; upper right figure, medial view; lower left figure, superior view; and lower right figure, lateral view of ankle. Calcaneofib indicates calcaneofibular ligament.

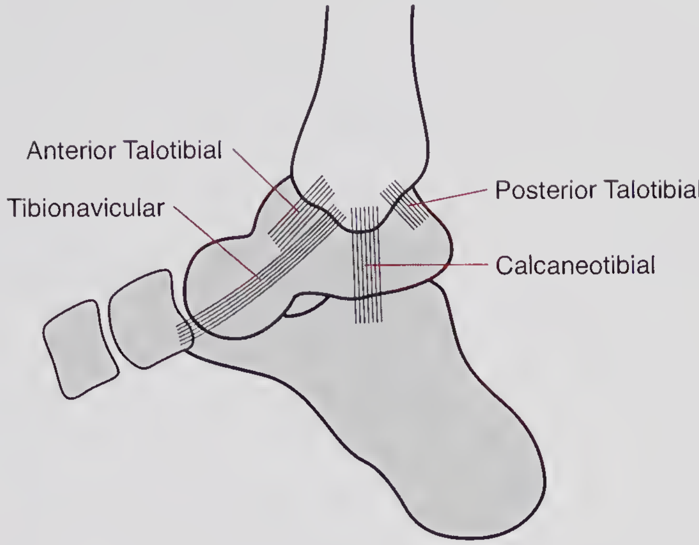


FIGURE 8.5

Medial Collateral (Deltoid) Ligaments Medial collateral ligaments, termed *deltoid ligament,* are anterior talotibial, tibionavicular, posterior talotibial, and calcaneotibial ligaments, so named by their sites of attachment.

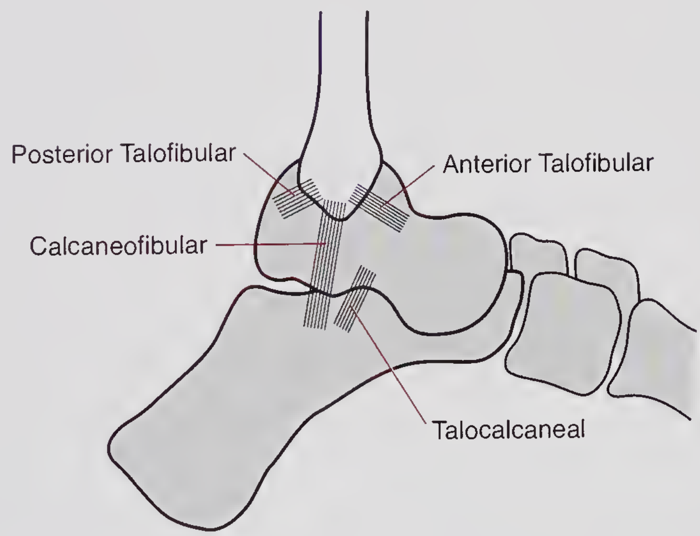


FIGURE 8.6

Lateral Collateral Ligaments of Ankle Lateral collateral ligaments of ankle are named by their sites of attachment: anterior talofibular, posterior talofibular, calcaneofibular, and talocalcaneal ligaments.

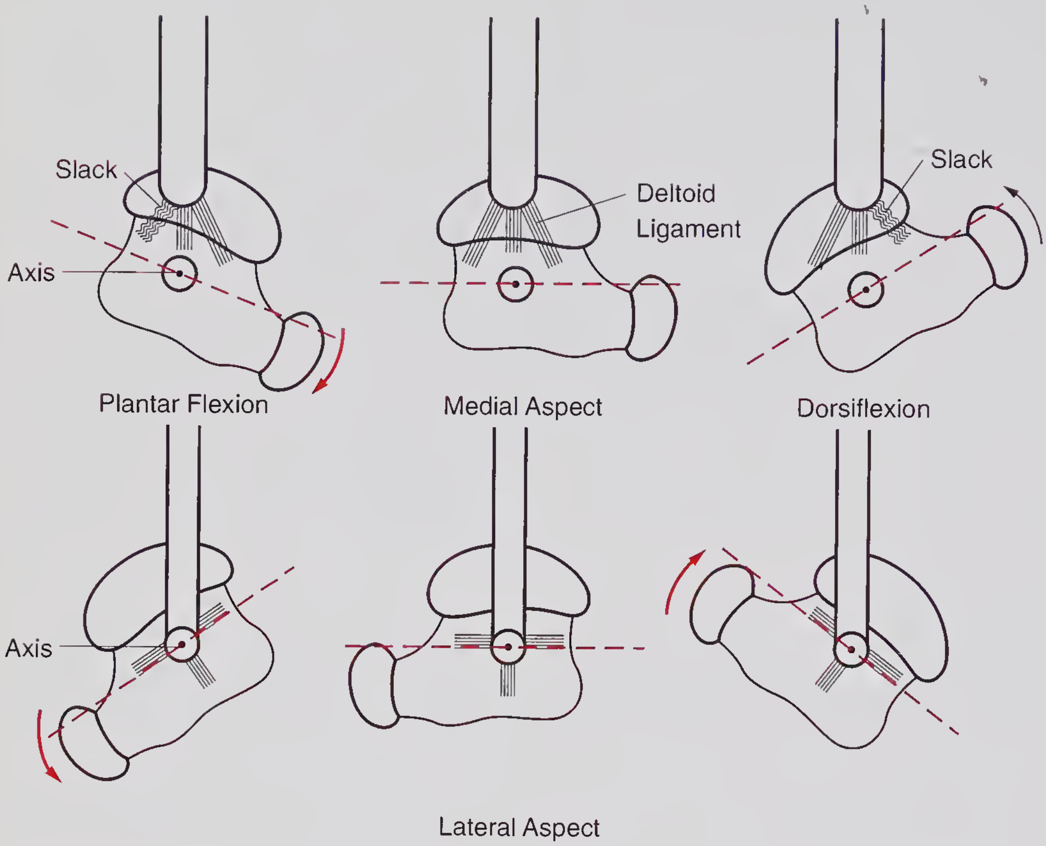


FIGURE 8.7

Relationship of Collateral Ligaments to Their Axis of Rotation Medial axis of rotation is eccentric and medial central, causing changes of medial and lateral collateral ligaments to change during plantar and dorsiflexion.

BONES AND JOINTS OF THE FOOT

There are 26 bones in the foot, which include 14 phalanges, 5 metatarsals, and 7 tarsal bones. The foot can be divided into 3 functional segments: the posterior, which includes the talus and calcaneus; the middle, which contains the 5 tarsal bones; and the anterior segment, which includes 5 metatarsal and 14 phalangeal bones (Figure 8.8).

The talus is the weight-bearing bone of the foot contained in the posterior segment. It is wedge-shaped, with the anterior portion wider than the hind section. It is contained in the ankle mortise formed by the malleoli of the fibula and the tibia. As stated in the previous section on the ankle, as the foot dorsiflexes, the anterior portion of the talus comes between the malleoli and widens the mortise. In plantar flexion, the narrower posterior portion of the talus enters the mortise and permits the malleoli of the mortise to approximate (Figures 8.9, 8.10).

The ligaments of the ankle support the talus-calcaneus in the ankle mortise and are subjected to elongation by substantial valgus and varus motion of the foot-ankle joint. The angle of rotation of the talus in the mortise influences the stability of the collateral ligaments in preventing injury due to overstretching or ligamentous tear or avulsion (Figures 8.11, 8.12).

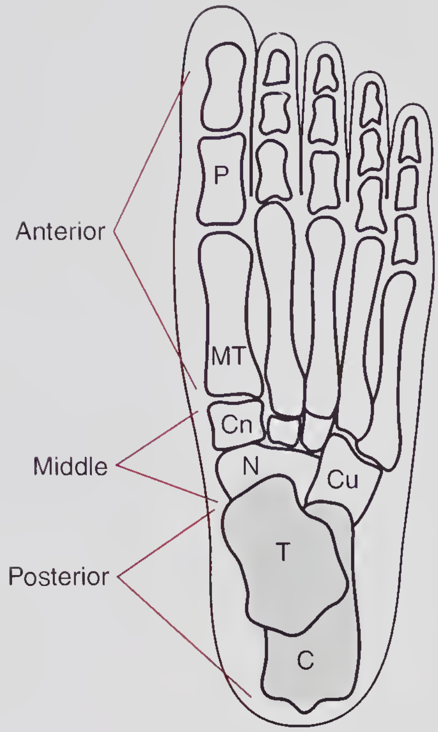


FIGURE 8.8

Functional Segments of Foot Three segments of foot are shown: anterior, which contains metatarsals (MT) and phalanges (P); middle, which contains tarsal bones—navicular (N), 3 cuneiform (Cn), and cuboid (Cu) —and posterior, which contains talus (T) and calcaneus (C).

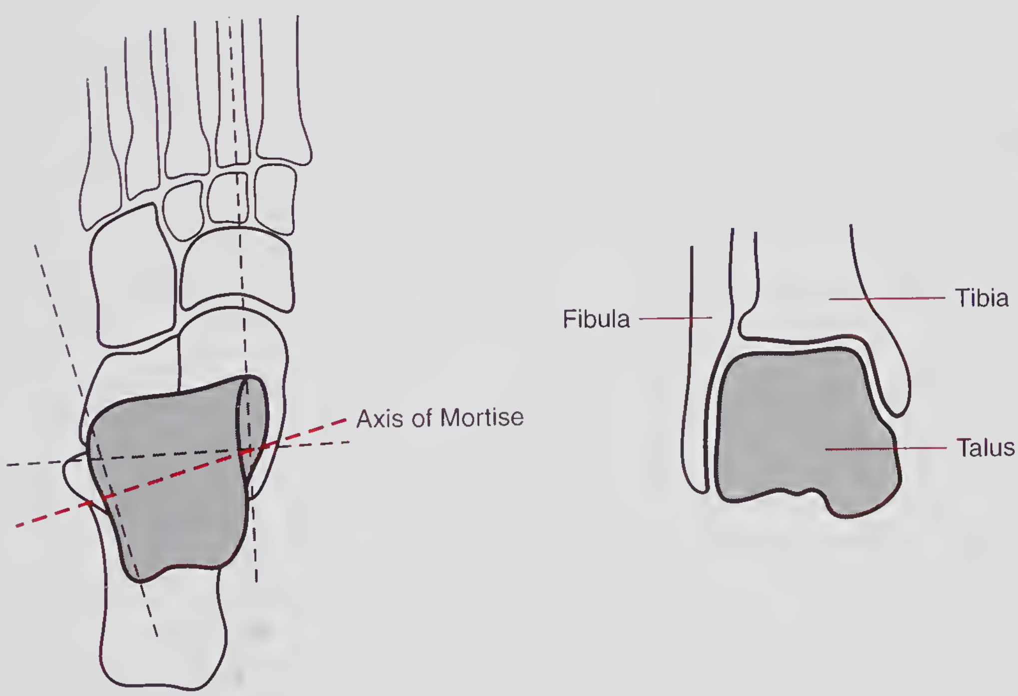


FIGURE 8.9

Superior View of Talus Viewed from above, talus is wedge-shaped; it is wider anteriorly than it is posteriorly. It inserts in mortise formed by fibular and tibial malleoli. Its axis on rotation is oblique to anterior posterior alignment of lower leg (knee to ankle).

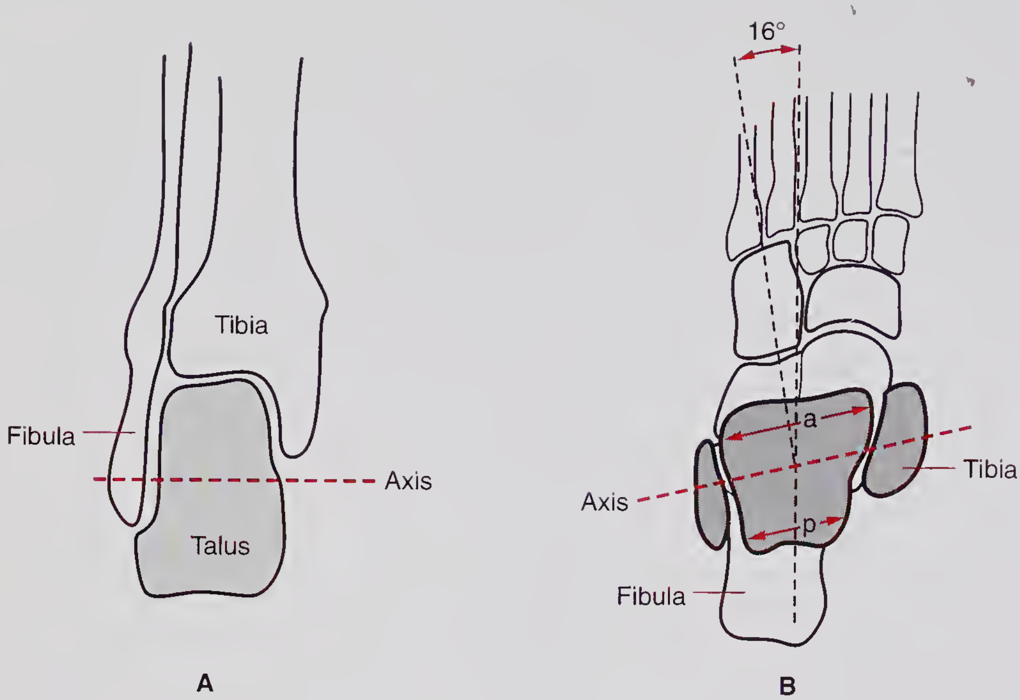


FIGURE 8.10

Axis of Rotation of Talus A, Anterior view of ankle joint shows talus between malleoli of fibula and tibia. B, Degree of lateral deviation (16 degrees) of talus and its axis of rotation. Wider aspect of talus (a) in contrast to posterior width (p).

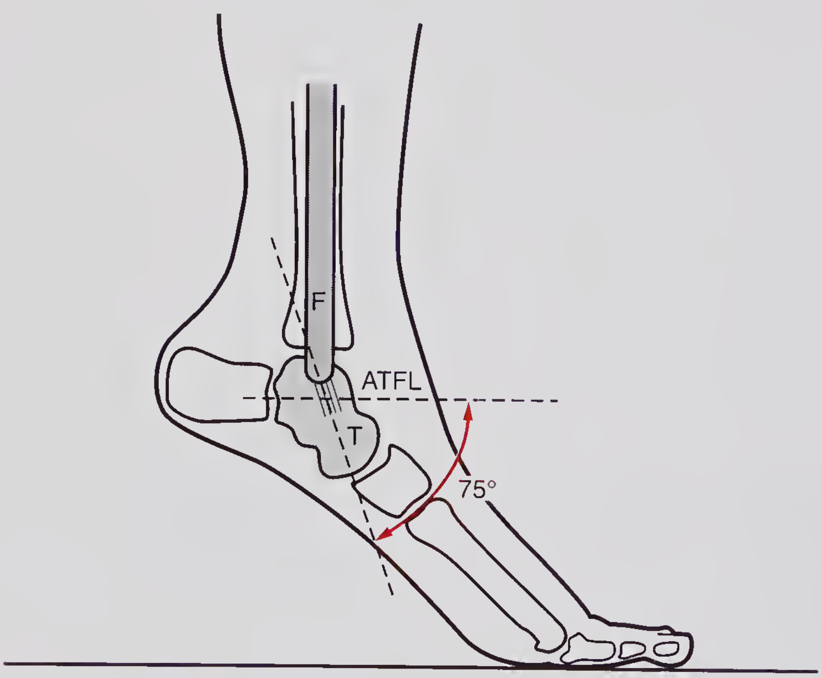


FIGURE 8.11

Anterior Talofibular Ligament During Plantar Flexion In extreme plantar flexion, anterior talofibular ligament (ATFL) becomes almost vertical (75 degrees from horizontal line). F indicates fibula; T, talus.

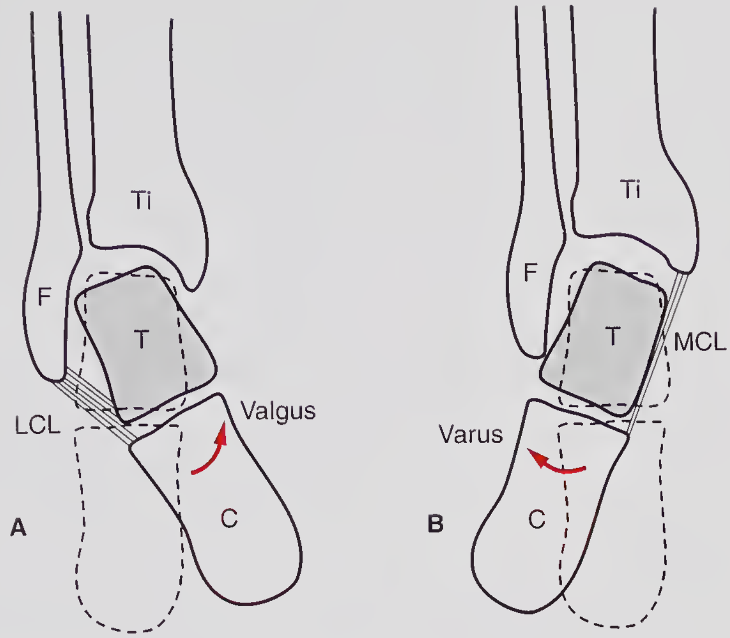


FIGURE 8.12

Medial Lateral Displacement of Ankle A, With severe foot valgus, lateral collateral ligament (LCL) becomes elongated and calcaneus (C) moves slightly in valgus direction on talus (T) within mortise. B, In varus, opposite occurs, elongating medial collateral ligaments (MCL). F indicates fibula; Ti, tibia.

Talocalcaneal Joint

Much of the inversion and eversion of the foot occurs at the talocalcaneal joint. Weight bearing on the foot is on the talus, which rests on the anterior two thirds of the calcaneus (os calcis). The major weight-bearing functional joints of the foot are the subtalar joint, the talonavicular cuboid joint, and the distal metatarsal-phalangeal joints. The center of gravity falls between the 2 navicular bones (Figures 8.13, 8.14, 8.15).

The talocalcaneal (subtalar) joint contains several joints in different planes that permit a slight degree of motion. The posterior joint of the superior surface of the calcaneus is convex, and the joint surface of the inferior aspect of the talus is concave. This relationship forms an incongruous joint that permits slight degrees of inversion and eversion. When the ankle joint is "locked," with the foot greatly dorsiflexed, all lower foot valgus and varus motion occurs at the talocalcaneal joint.

The entire body and part of the head of the talus rests on the anterior two thirds of the calcaneus and projects slightly in front of it. The anterior facets of the subtalar joint consist of 2 similar facets on the superior aspect of the calcaneus and the inferior aspect of the body and neck of the talus. The facets on the talus are convex and those on the calcaneus are concave. This is the opposite of the posterior facets. This asymmetry forms an incongruous joint with limited motion (Figures 8.16, 8.17, 8.18).

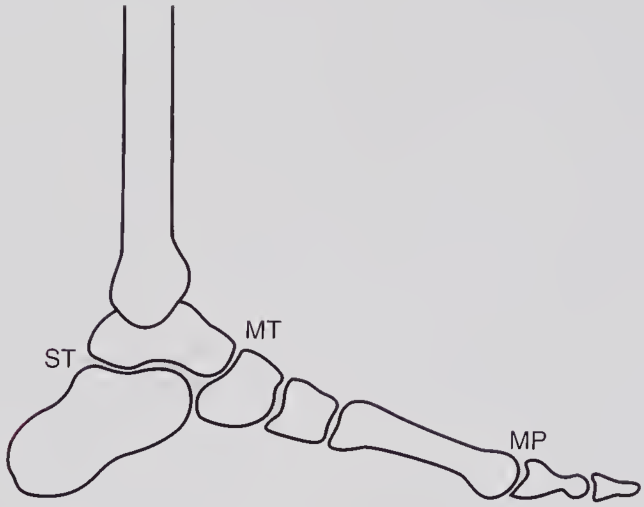


FIGURE 8.13

Major Functional Weight-Bearing Joints of Foot Three major weight-bearing functional units of foot are subtalar joint (ST), which is between talus and calcaneus, midtarsal (MT), which is between talus and navicular and cuneiform bones; and metatarsal phalangeal (MP) joints.

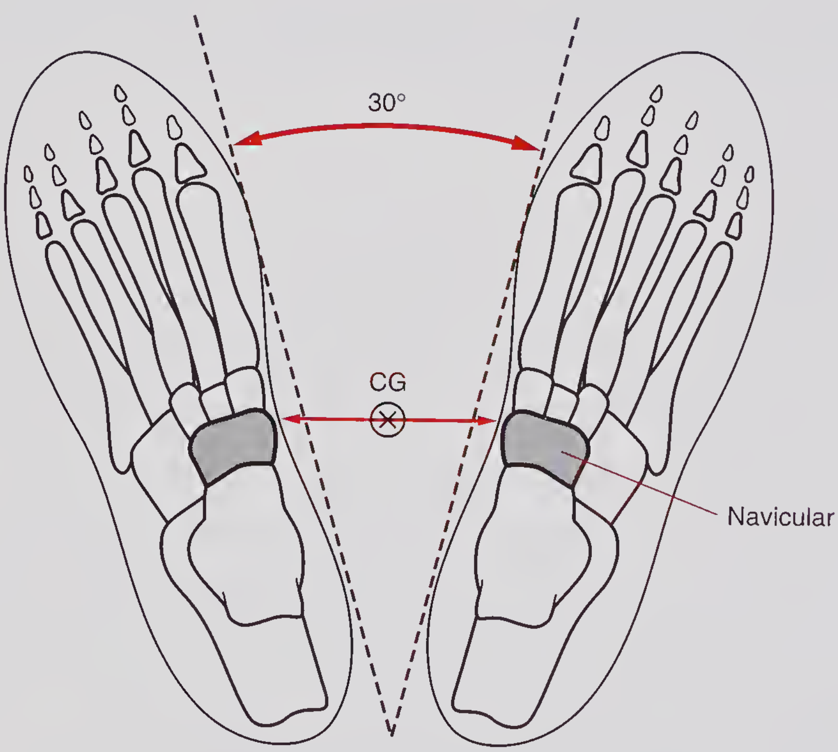


FIGURE 8.14

Center of Gravity of Weight-Bearing Feet Center of gravity (CG) is midway between 2 navicular bones of feet that, on normal standing, usually have feet turned outward 30 degrees.

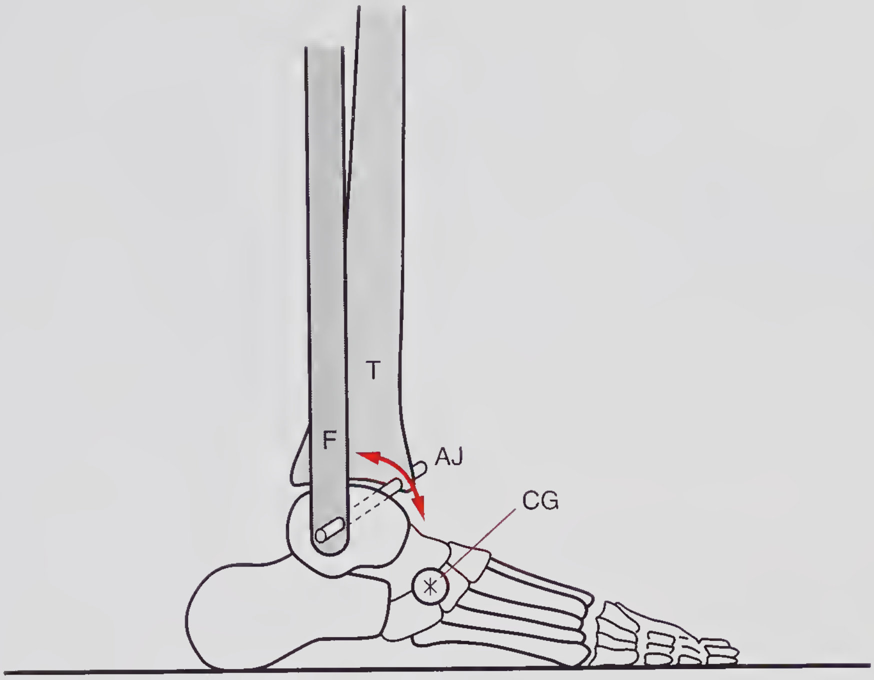


FIGURE 8.15

Ankle Joint Relationship to Center of Gravity Axis of rotation of ankle joint (AJ) is posterior to center of gravity (CG) of foot. Heel lever arm is shorter than forefoot lever arm; hence, there is some rotation of hind forefoot. F indicates fibula; T, tibia.

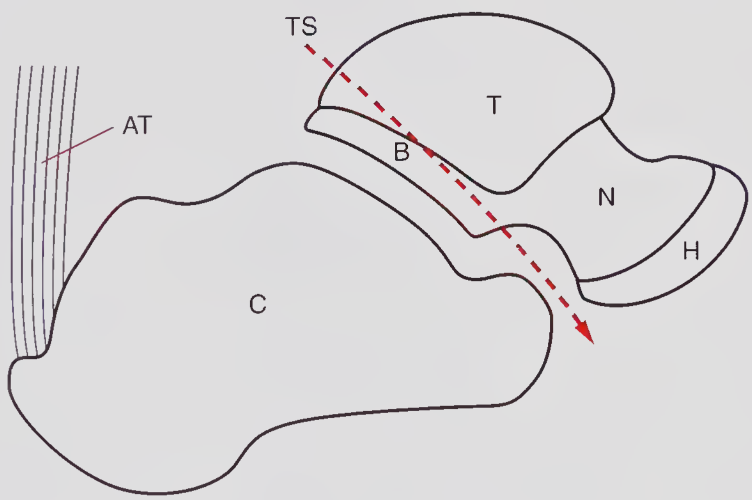


FIGURE 8.16

Lateral Aspect of Talocalcaneal Joint Talus (T) is divided into body (B), neck (N), and head (H). It articulates with calcaneus (C). Joint forms sinus tarsi (tarsal canal; TS), in which talocalcaneal ligament exists. AT indicates Achilles tendon.

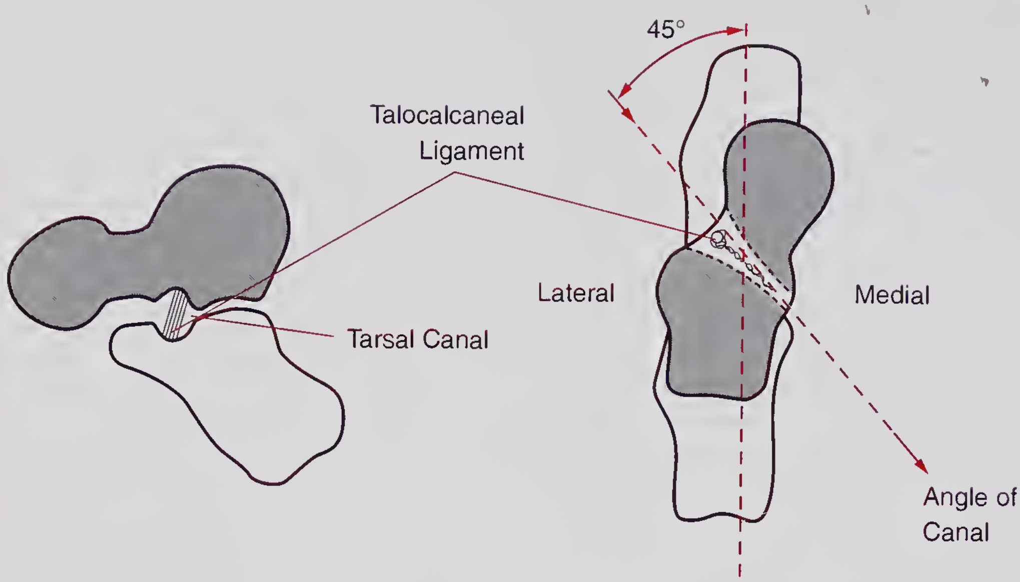


FIGURE 8.17

Talocalcaneal (Subtalar) Joint Talus and calcaneus are joined by 3 facets: anterior, middle, and posterior. The talocalcaneal joint runs oblique course and forms tarsal canal (sinus tarsi), which contains talocalcaneal ligament that binds 2 bones. Rounded end of ligament is termed *cervicis ligament*. Lateral and medial indicate aspects of talocalcaneal joint.

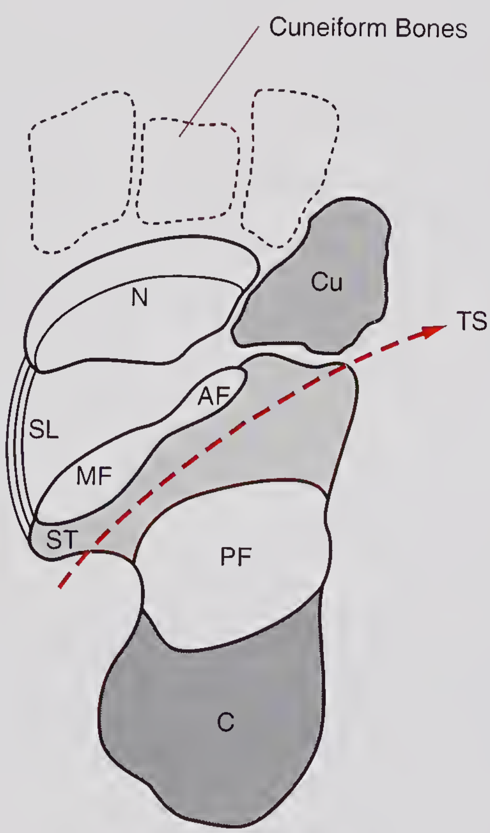


FIGURE 8.18

Bed of Talus on Calcaneus Spring ligament (SL) looks down on calcaneus (C). With talus removed, facets can be seen—middle facet (MF), anterior facet (AF), and posterior facet (PF).Sustentaculum tali (ST) is site of attachment of spring ligament. Tarsal canal (TS), navicular bone (N), and cuboid (Cu) bone are shown for orientation.

Talocalcaneal Ligaments

There are 2 major ligaments connecting the talus to the calcaneus: the interosseous talocalcaneal ligament and the lateral talocalcaneal ligament. Because both are relatively weak ligaments, the talocalcaneal joint is supported mainly by the calcaneal-fibular portion of the lateral collateral ligaments of the ankle and the calcaneotibial portion of the medial (deltoid) ligaments of the ankle. That joint is also supported by the tendons of the musculi peroneus longus, peroneus brevis, flexor hallucis longus, tibialis posterior, and flexor digitorum longus.

All tendons crossing the ankle joint pass forward to insert on the foot. Four tendons pass anteriorly to the joint axis and 5 pass posteriorly. These tendons also resist forward displacement of the foot and ankle (Figure 8.19, 8.20).

The talocalcaneal joint is divided by the interosseous ligament into posterior and anterior portions. The posterior talocalcaneal joint space has a synovial cavity, known as the *subtalar joint*. The anterior joint space shares a synovial cavity with the talonavicular joint and is termed the *talocalcaneal navicular joint*. The talocalcaneal navicular joint is formed

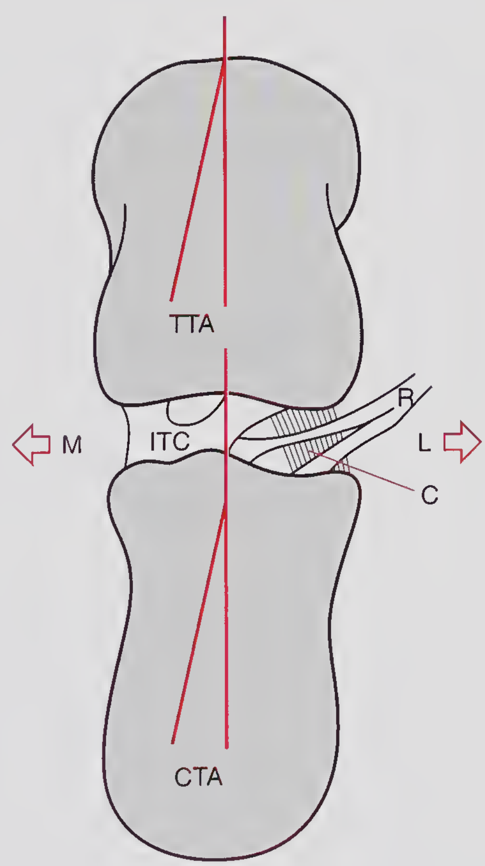


FIGURE 8.19

Talocalcaneal Ligaments Ligaments of talocalcaneal joint are interosseous talocalcaneal ligament (ITC) and cervical ligament (C). Lines drawn through talus (T) and tibia form tibiotalar angle (TTA), and lines drawn through talus and through calcaneus form tibiocalcaneal angle (CTA). R indicates retinacula; M, medial; and L, lateral side.

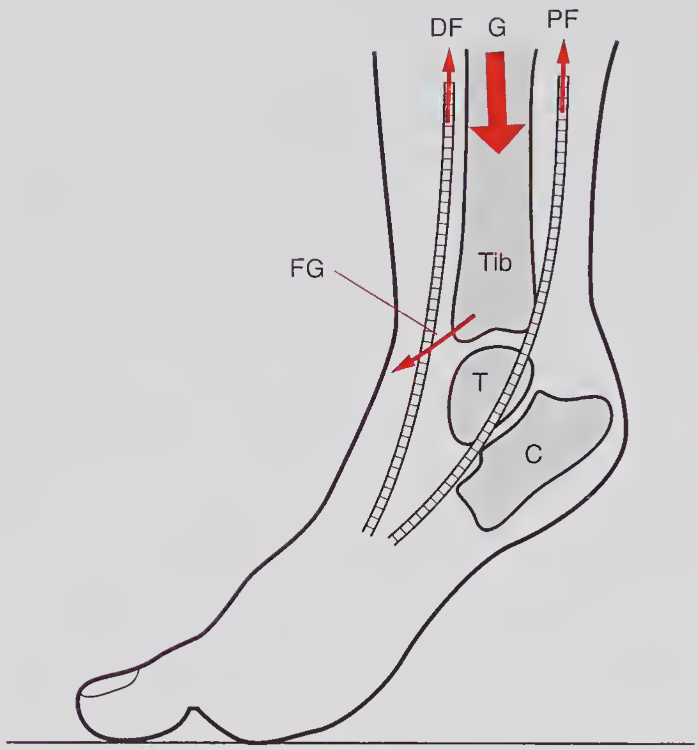


FIGURE 8.20

Prevention of Anterior Shear of Leg on Foot Gravity (G) and weight of body (large arrow) tend to cause forward shear force (small arrow) of tibia (Tib) on talus (T) and talus on calcaneus (C). This shear force is minimized by ankle dorsiflexors (FG) and plantar flexors. DF indicates dorsiflexors; PF, plantar flexors.

superiorly by the posterior surface of the navicular bone and below by the middle and anterior facets of the talus and between the navicular and sustentaculum tali by a firm ligament. This ligament, the plantar calcaneonavicular ligament, is also called the *spring ligament*.

The interosseous talocalcaneal ligament runs the length of the tarsal tunnel. At its fibular end, it thickens into a fibrous band that connects the 2 small tubercles opposing each other from the talus and the calcaneus. This band is termed the *ligamentum cervicis* and allows some rotation of the talus on the calcaneus.

The interosseous talocalcaneal ligament runs perpendicular to the subtalar axis, and the ligamentum cervicis lies laterally. Thus, the ligamentum cervicis tenses during inversion of the foot and becomes slack during eversion. Small bony processes located on the lateral inferior aspect of the body of the talus impinge on an opposing tubercle on the calcaneus, and there is limited inversion and eversion (Figure 8.21).

Talonavicular Joint

The rounded head of the talus fits into the cupped surface of the navicular bone. Motion of that joint is rotation about an axis, which slants downward forward and medially. Some gliding is permitted, allowing inversion and eversion. This joint, along with the calcaneocuboid joint, is part of the transverse tarsal joint.

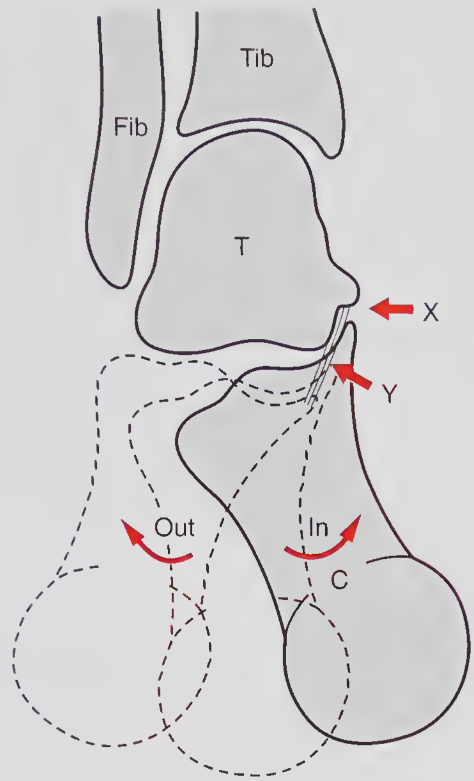


FIGURE 8.21

Mechanical Limitation of Eversion and Inversion When talus (T) is fixed in mortise of tibia (Tib) and fibula (Fib), inversion and eversion (In and Out, respectively) is limited. There is mechanical impingement of superior process of calcaneus (C) on inferior process of talus on inversion (X). Eversion (Out) is limited by a ligament (Y).

Calcaneocuboid Joint

The joint between the calcaneus and the cuboid bone is an accessory joint formed by the anterior surface of the calcaneus, which is convex. The calcaneus inserts into the concave surface of the posterior aspect of the cuboid. It allows some inversion and eversion.

Transverse Tarsal Joint

The transverse tarsal joint consists of the talonavicular and the calcaneocuboid joints. This joint has been termed the "surgeon's tarsal joint," the midtarsal joint, or the Chopart joint, as it is the frequent site of amputation of the foot.

Movements about this joint include supination and pronation (rotation about a long anteroposterior axis of the foot), abduction and adduction (horizontal movements of the forepart of the foot away from the sagittal plane), and "inversion-eversion" (turning of the sole of the foot to face the sole of the opposite foot). Inversion is a combination of supination and adduction, and eversion is a combination of pronation and abduction. Inversion and eversion are movements of the entire foot except the talus, involving all the joints below and in front of the talus (Figure 8.22).

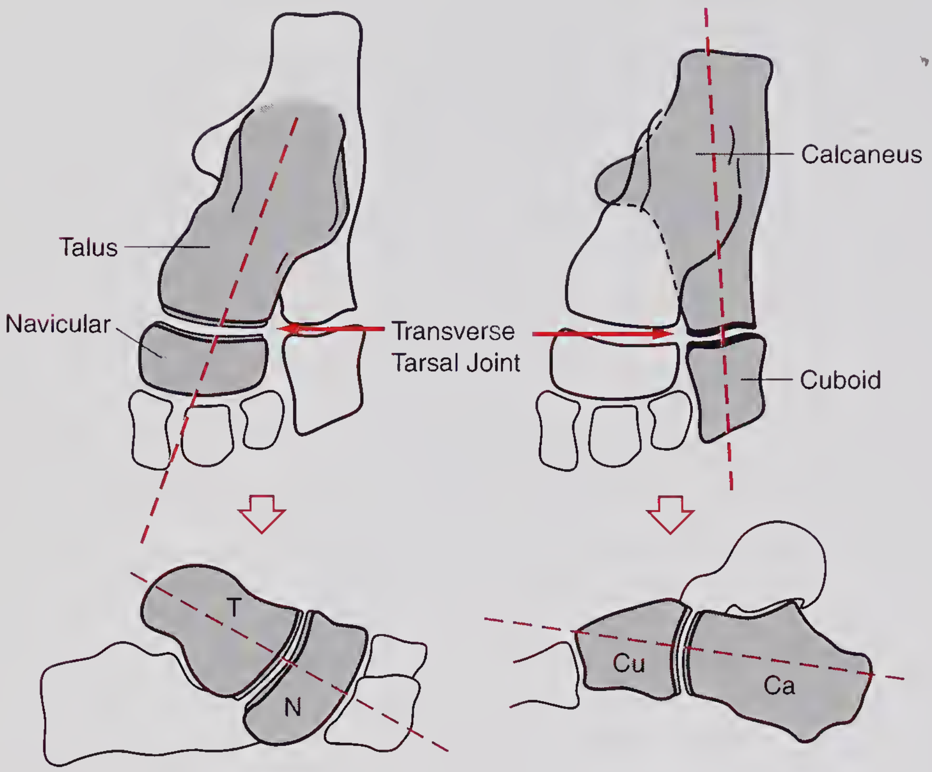


FIGURE 8.22

Transverse Tarsal Joint Transverse tarsal joint is composed of joints between talus (T) and navicular bone (N) and joint between anterior calcaneus (Ca) and cuboid bones (Cu).

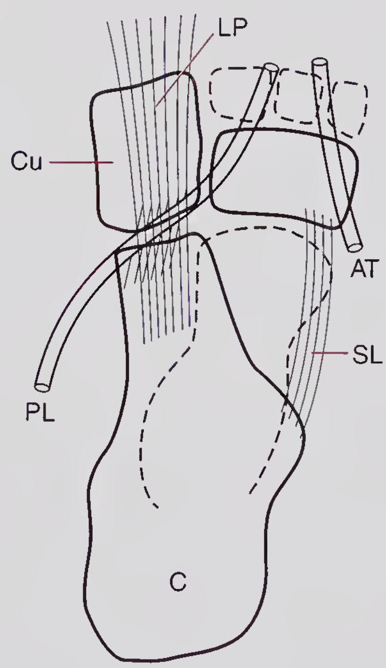


FIGURE 8.23

Plantar Ligaments Long plantar ligament (LP) extends from plantar surface of calcaneus (C) to cuboid bone (Cu). Its superficial fibers extend to bases of second third, fourth, and fifth metatarsals (not shown here). These fibers convert groove in cuboid into tunnel for peroneus longus tendon (PL). Short plantar ligament stretches from anterior tubercle (AT) of calcaneus to cuboid. Spring ligament (SL) connects calcaneus to navicular bone.

All of the bones of the transverse tarsal joint are supported by 2 ligaments: the long plantar and the short plantar. The long plantar ligament extends from the plantar surface of the calcaneus to the ridge of the cuboid bone. Its most superficial fibers extend further to attach to the bases of the second, third, and fourth metatarsals. These fibers convert the groove of the cuboid into a tunnel containing the peroneus longus muscle tendon, which proceeds distally through a sulcus in the base of the fifth metatarsal bone. The short plantar ligament extends from the anterior tubercle of the calcaneus to the cuboid. This ligament specifically unites the calcaneocuboid joint (Figure 8.23).

ARCHES OF THE FOOT

There are 4 arches of the foot: 3 across (transverse arches) the bones of the foot and the fourth (longitudinal arch) viewing the foot from the side.

Transverse Arches

The transverse arches are the tarsal, posterior metatarsal, and anterior metatarsal (Figure 8.24).

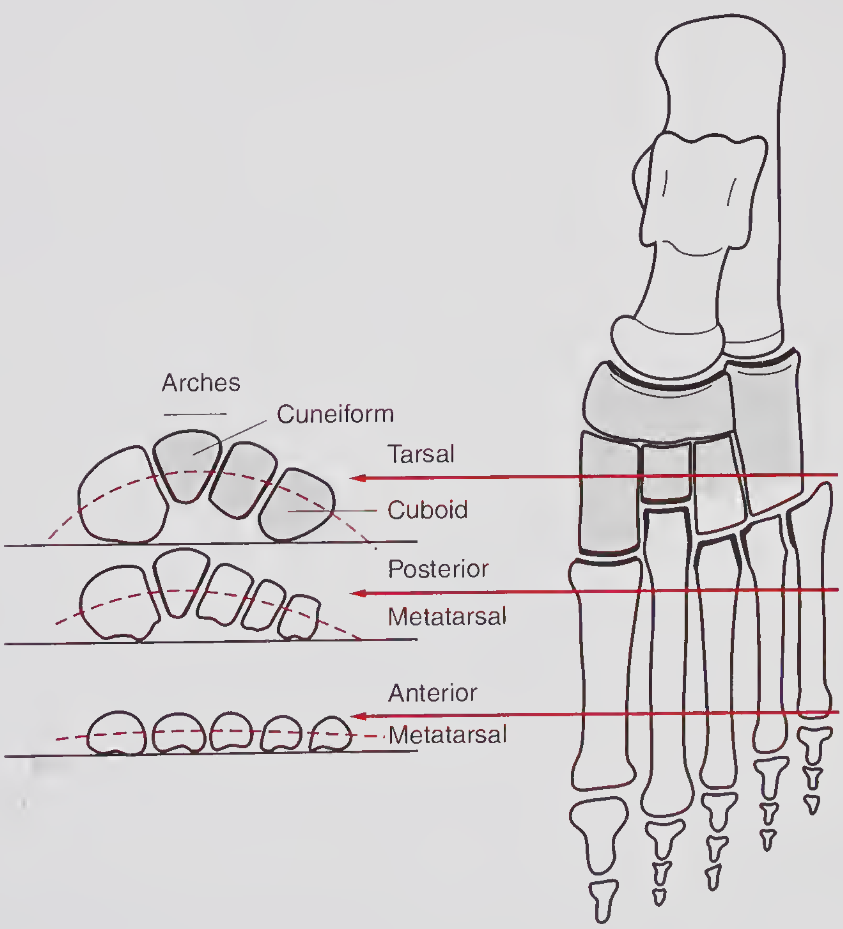


FIGURE 8.24
Transverse Arches of Foot Three transverse arches of foot: tarsal, posterior metatarsal, and anterior metatarsal.

The tarsal arch is formed by the navicular, the cuboid, and the 3 cuneiform bones that by their shapes and juncture form a bony arch resembling a "keystone arch." They are reinforced by ligaments (Figure 8.25).

The transverse arch, otherwise known as the *posterior metatarsal arch*, is formed by the bases of each metatarsal bone. The shapes of the metatarsi form the arch and permit stability merely by their configuration even with the weight of the body being borne on the foot (Figure 8.26).

Longitudinal Arches

Viewed from the side, the foot has 2 longitudinal arches dependent on viewing being from the medial or lateral side. The arches are maintained by virtue of the specific shapes of all the component bones and are reinforced by the plantar fascia.

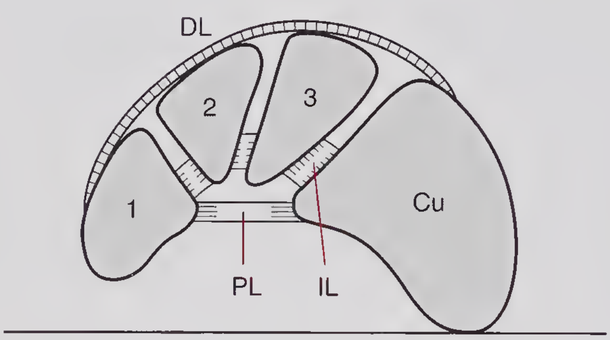


FIGURE 8.25

Ligaments of Tarsal Arch There are 3 major ligaments crossing and binding tarsal bones to form arch: dorsal ligament (DL), internal ligament (IL), and plantar ligament (PL). 1, 2, and 3 indicate cuneiform bones; CU, cuboid bone.

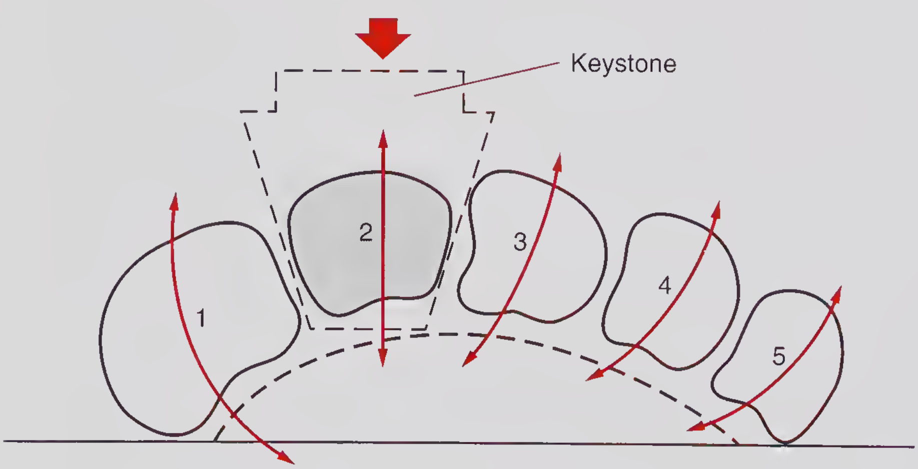


FIGURE 8.26

Transverse Arch Transverse arch otherwise known as posterior metatarsal arch is formed by base of 5 metatarsal bones. Although there is some movement between each bone they are relatively fixed. Base of second metatarsal (2) is wedge shaped and resides as keystone bone of arch. All bones rotate about this fixed second metatarsal (curved arrows).

Lateral Longitudinal Arch

The lateral longitudinal arch is formed by the calcaneus, cuboid bone, and the fourth and fifth metatarsals. It is a small arch that bears the body weight. It can "flatten" at the hinge joint between the cuboid and the fourth and fifth metatarsals.

Medial Longitudinal Arch

The medial longitudinal arch is formed by the calcaneus, talus, the 3 cuneiform bones, and the 3 medial metatarsals. It is a higher arch than is the lateral longitudinal arch, with its summit at the head of the talus and the navicular bones. The posterior tibial muscle tendon passes under the spring ligament and inserts on the second, third and fourth metatarsal bones at their bases. Any "flattening" of the arch occurs at the joint between the talus and the navicular bones (Figures 8.27, 8.28).

Plantar Fascia

The plantar fascia, which supports the arches, originates from medial tubercle of the anteromedial aspect of the calcaneus and proceeds anteriorly to split into 5 bands, each of which attaches to a digit. Each distal band splits at the metatarsophalangeal joint to attach to the inner and outer aspects of that joint. Through this distal division pass the short and long flexor tendons. Occasionally there is a short lateral fibrous band that attaches to the base

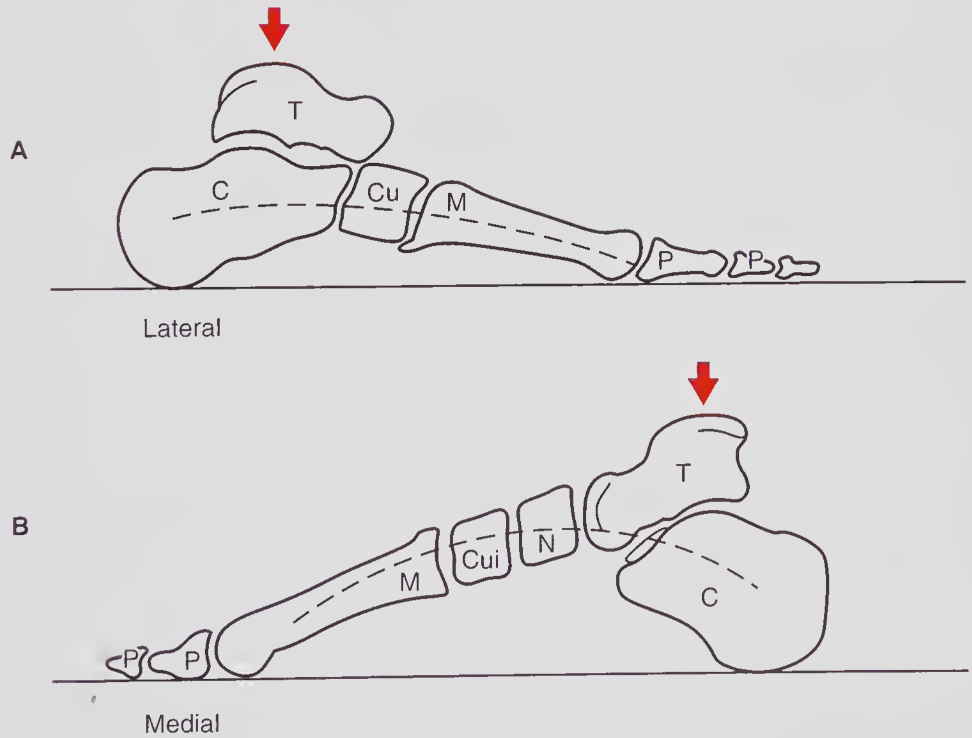


FIGURE 8.27

Longitudinal Arches A, Viewed from side, lateral longitudinal arch contains calcaneus (C), talus (T), cuboid (Cu), metatarsals (M), and lateral phalanges (P). B, Medial longitudinal arch is formed by talus (T), calcaneus (C), navicular bones (N), cuneiform bones (Cui), and 3 medial metatarsals (M).

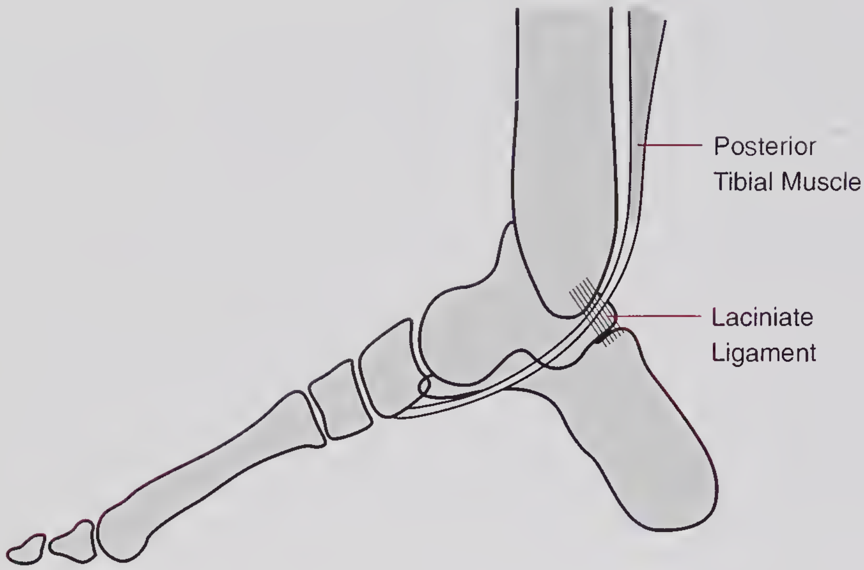


FIGURE 8.28

Posterior Tibial Tendon Posterior tibial tendon arises from upper two thirds of interosseous membrane between tibia and fibula, and its tendon attaches to base of second, third, and fourth metatarsal bones. It passes behind medial malleolus under laciniate ligament, which forms tunnel. By its passage, it forms pulley arrangement, causing plantar flexion and foot inversion.

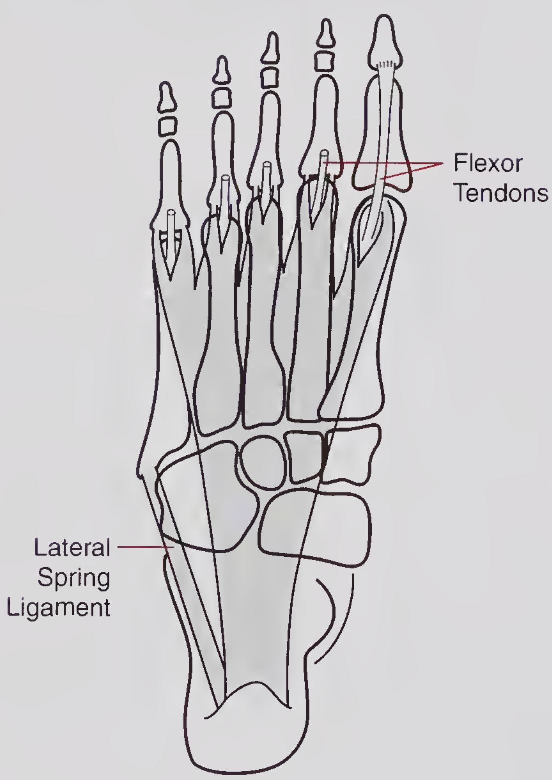


FIGURE 8.29

Plantar Fascia Plantar fascia originates from calcaneal tuberosity and passes anteriorly toward each digit. It splits into 5 bands with each again dividing at metatarsal phalangeal joints to form a tunnel, through which flexor tendons pass. Fibrous band is often found on lateral margin, which attaches to base of fifth metatarsal bone base.

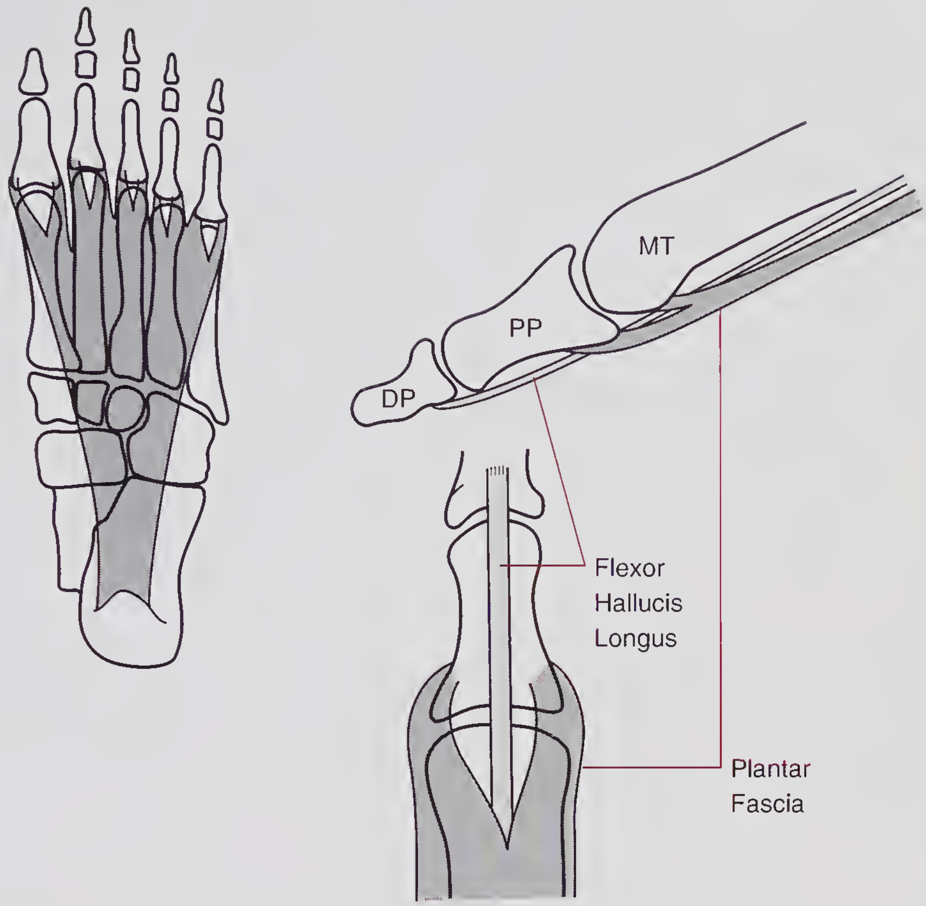


FIGURE 8.30

Anterior Portion of Plantar Fascia At distal anterior margin of plantar fascia, fascial bands divide, forming tunnel through which flexor tendons pass. Metatarsal (MT), proximal phalanx (PP), and distal phalanx (DP) are shown.

of the fifth metatarsal bone. This is termed the *lateral spring ligament* (Figures 8.29, 8.30).

The function of the plantar fascia remains obscure, but it probably supports the longitudinal arches, which are solid by virtue of the structure and relationship of all the bones and their capsules, forming individual keystone structures.

The plantar fascia is made firmer from extension of the toes, because the anterior distal bands of the fascia after their division attach to the base of the proximal phalanges; thus, extension of the proximal phalanges causes increased tension of the plantar fascia (Figures 8.31, 8.32).

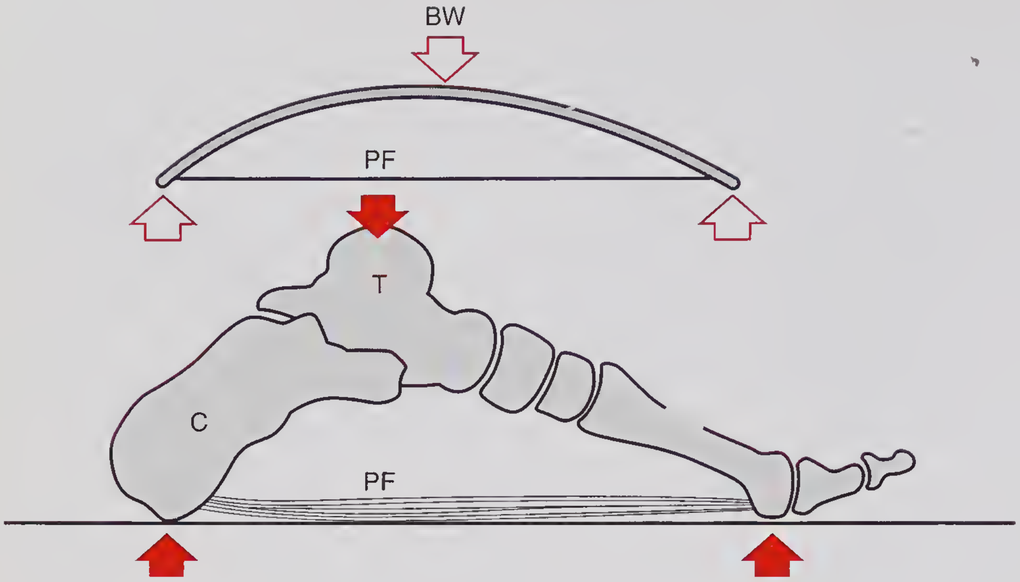


FIGURE 8.31

Mechanism of Plantar Fascia on Longitudinal Arch Body weight (BW) is borne on talus (T), which is apex of longitudinal arch. Upper figure shows weight bearing on calcaneus (C) and heads of metatarsi. Mechanism of plantar fascia (PF) is that of bow and string.

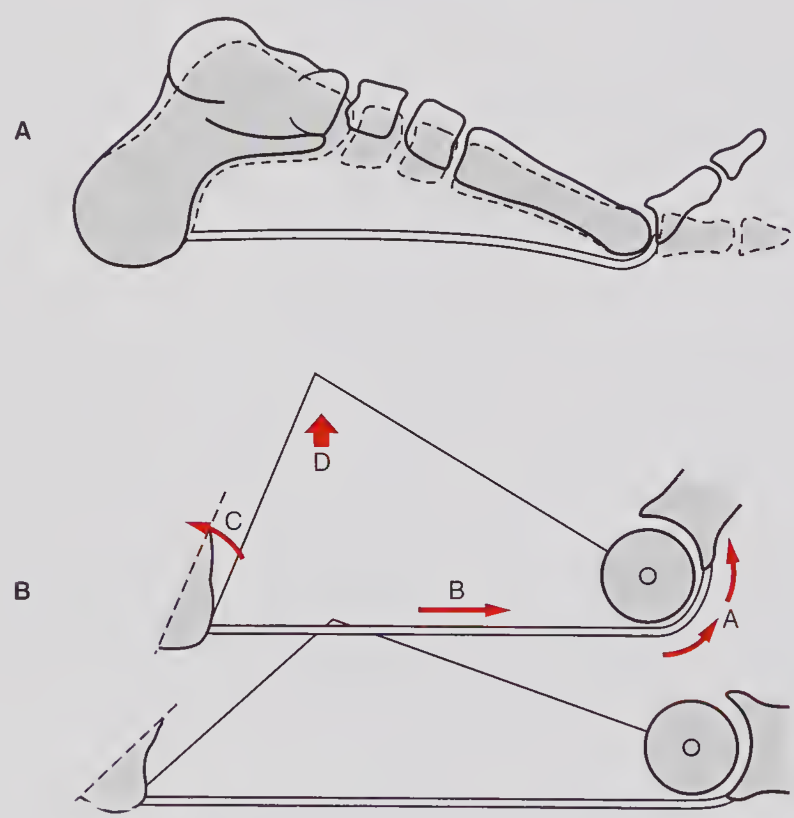


FIGURE 8.32

Effects on Plantar Fascia by Toe Extension A, Longitudinal arch flattens (shaded area) on weight bearing. B, Effect of toe extension (A curved arrows) on fascia (B arrow) and calcaneus (C arrow). Arch should increase (D) but does not because of body weight.

METATARSOPHALANGEAL JOINTS

The distal ends of the metatarsal bones are curved in an oblique manner. They articulate with the proximal ends of the phalanges that are concave. They form an incongruous joint in that they have different curvatures, and flexion from neutral position must glide before there is rotation about the axis of rotation of the metatarsal head. All toes, especially the big toe, hyperextend physiologically (Figure 8.33, 8.34).

There are 2 phalanges in the first (big) toe and 3 phalanges in all the other toes. Their projections normally find the big toe the longest, followed by all toes in sequence, with the fifth toe being the shortest (Figure 8.35).

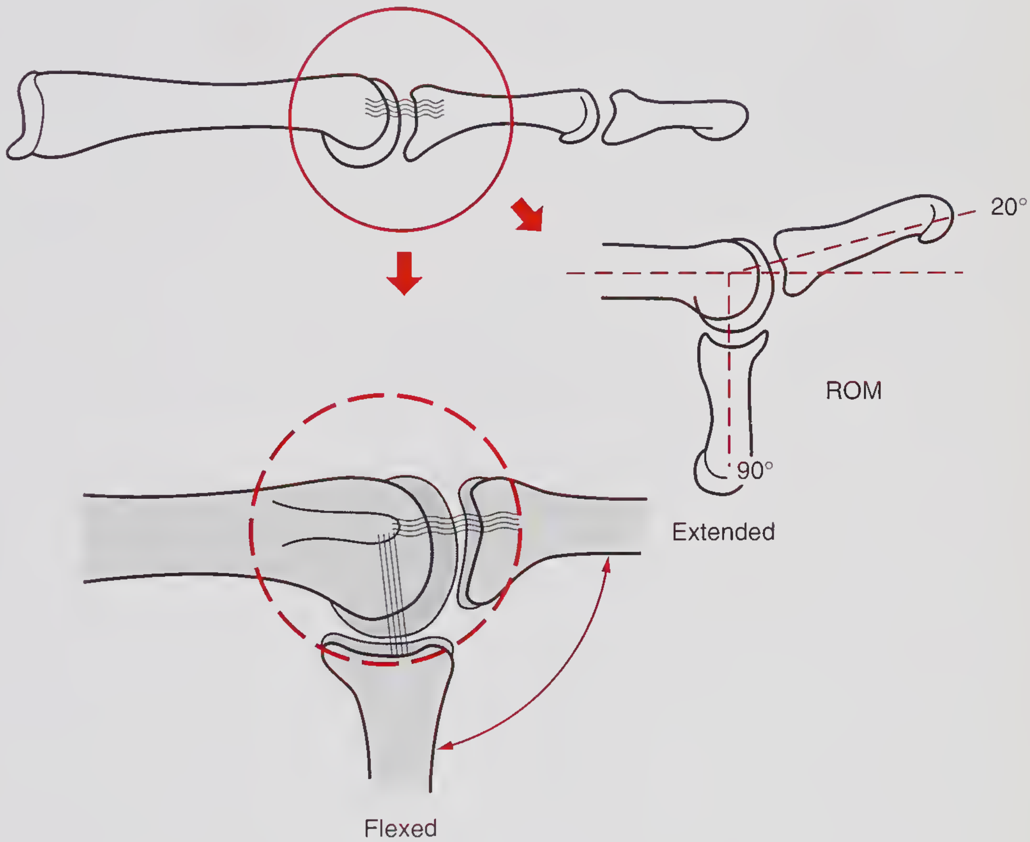


FIGURE 8.33

Movements of Metatarsal-Phalangeal Joint Joint axis of rotation is eccentric to center (dashed circle) and thus in flexion, which is possible to 90 degrees. Initial flexion is a downward glide until center of rotation (axis) is reached, causing toe to flex. Hyperextension (to 20 degrees) is possible. ROM indicates range of motion.

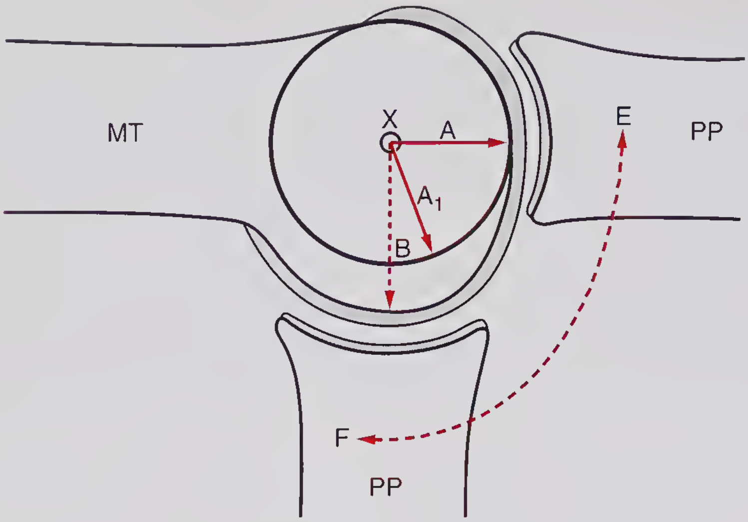


FIGURE 8.34

Metatarsal-Phalangeal Joint Distal end of metatarsal is covered with cartilage and is ovoid (B from axis of rotation) compared with full circle (A). As proximal phalanx (PP) flexes on metatarsal (MT), E to F, it glides down before rotating.

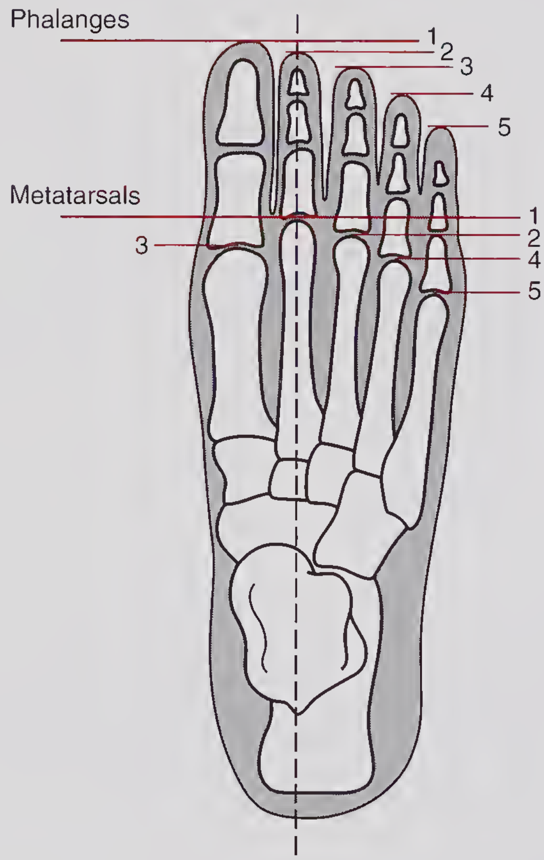


FIGURE 8.35

Relative Lengths of Toes Full length of each toe follows this sequence: 1>2>3>4>5. Length of metatarsals, however, differs, with metatarsal 2 being longest, third metatarsal next longest and so on: 2>3>1>4>5.

TENDON ATTACHMENTS TO TOES

The tendons of the leg muscles attach to the bones of this segment of the foot differently with each toe. As the first (big toe) has only 2 phalanges, it flexes differently than do the others. The first toe "presses" down the others, which flex in a "gripping" manner (Figures 8.36, 8.37, 8.38).

MUSCLES OF THE FOOT

The muscles that originate away from the foot yet act on the foot are considered to be *extrinsic* foot muscles. The *intrinsic* muscles of the foot originate and insert on bones in the foot itself.

Extrinsic Foot Muscles

Of the major extrinsic muscles of the foot, the plantar flexors are the musculi gastrocnemius, soleus, tibialis posterior, flexor digitorum longus, and flexor hallucis longus. The latter 3 are plantar flexor as their primary

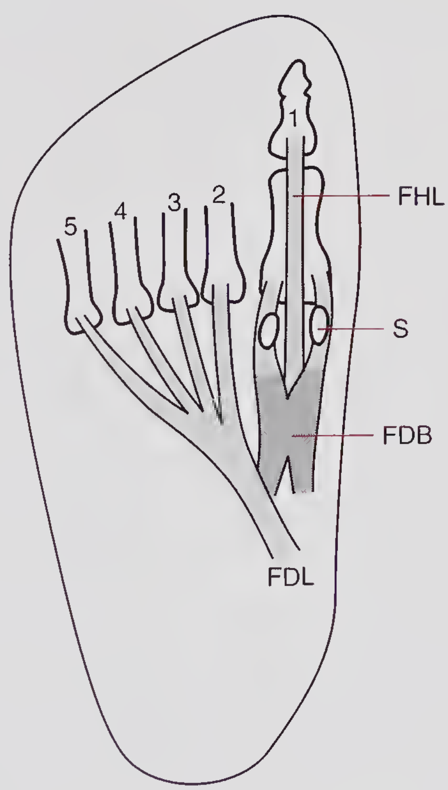


FIGURE 8.36

Flexor Tendon Attachments Flexor hallucis longus (FHL) tendon attaches to base of distal phalanx and flexor digitorum brevis (FDB), divides, and attaches to base of proximal phalanx. Sesamoid bones (S) are within flexor digitorum brevis tendons. Flexor digitorum longus (FDL) tendons attach to base of proximal phalanges 2, 3, and 4.

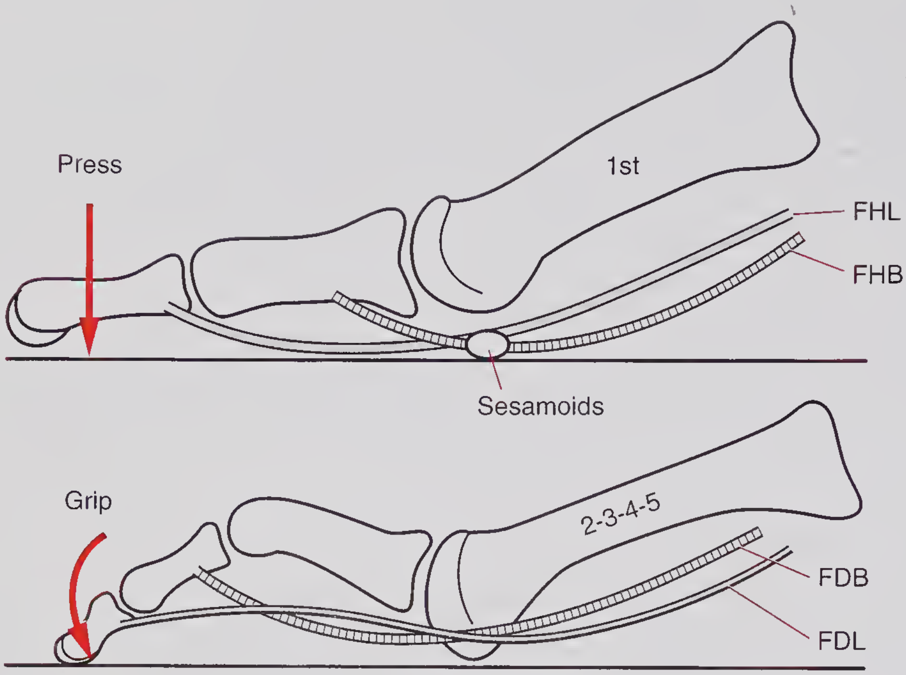


FIGURE 8.37

Action of Toe Flexors Flexor tendons of first (big) toe cross 2 joints and "presses" distal phalanx on ground. Flexor tendons—flexor hallucis longus (FHL) and flexor hallucis brevis (FHB)—of first toe are shown. Sesamoid bones within flexor hallucis brevis acts as fulcrum to flexor action. Flexor action of other toes (2, 3, 4, and 5) cross 3 joints and "grip" the ground when they flex. Tendons are flexor digitorum longus (FDL) and flexor digitorum brevis (FDB).

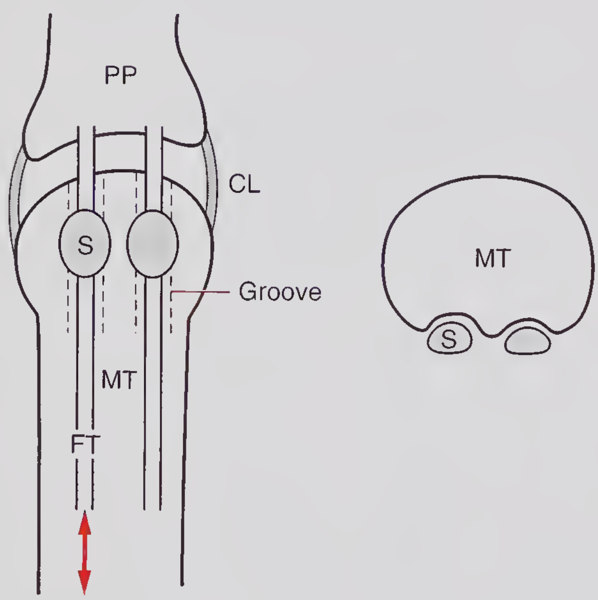


FIGURE 8.38

Sesamoid Bones Sesamoid bones (S) contained within tendons of flexor hallucis brevis (FT, flexor tendon) move in a groove on plantar surface of metatarsal bones (MT). These grooves guide movement of bones and thus tendons. Flexor hallucis brevis attaches to proximal phalanx (PP), and metatarsal-phalangeal joint is fortified by collateral ligaments (CL).

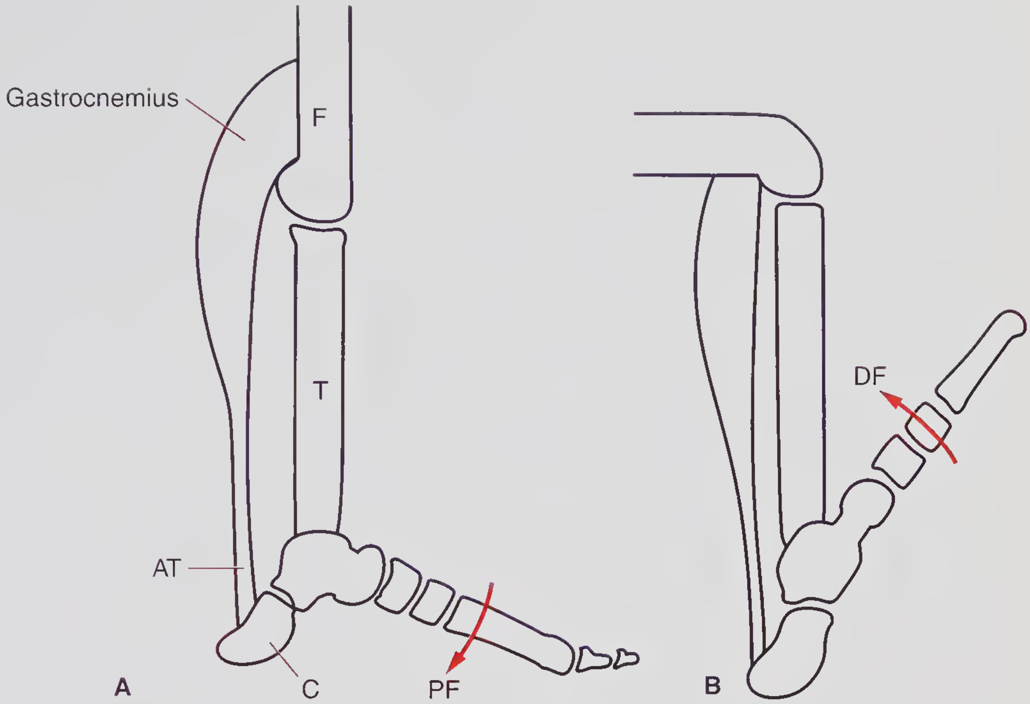


FIGURE 8.39

Gastrocnemius Muscle Function A, Schematically, gastrocnemius muscle (gastroc) attaches from femur (F) and inserts via Achilles tendon (AT) to calcaneus (C), plantar flexing foot (PF). B, Foot decelerates as it dorsiflexes (DF). T indicates tibia.

function, but the gastrocnemius and soleus muscles are the prime plantar flexors.

The gastrocnemius muscle originates above the knee joint by 2 heads, each being connected to opposing femoral condyles. Halfway down the leg, the gastrocnemius muscle flattens into the Achilles tendon, which attaches to the posterior aspect of the calcaneus bone.

The function of the gastrocnemius muscle is to elevate the total body from the standing position by plantar flexing the foot at the ankle. Because it is oblique to the ankle mortise, it is also a powerful supinator of the subtalar joint when the foot is prone on the ground. It decelerates ankle dorsiflexion and, when the foot is on the ground, the origin and insertion change places (Figure 8.39).

The soleus muscle originates from the upper tibia and fibula below the knee joint and lies under the gastrocnemius muscle. Unlike the gastrocnemius, the soleus is a 1-joint muscle that does not act on the knee. With the knee flexed, the soleus muscle is the prime ankle plantar flexor, and the gastrocnemius becomes ineffectual.

All the tendons that pass under and behind the malleoli are considered plantar flexors. These include the tibialis posterior, flexor digitorum longus, and flexor hallucis longus. When a person stands up on the toes, these muscles are considered to exert only 5% of the force needed to lift the body. The major ankle flexor is the gastrocnemius muscle (Figure 8.40).

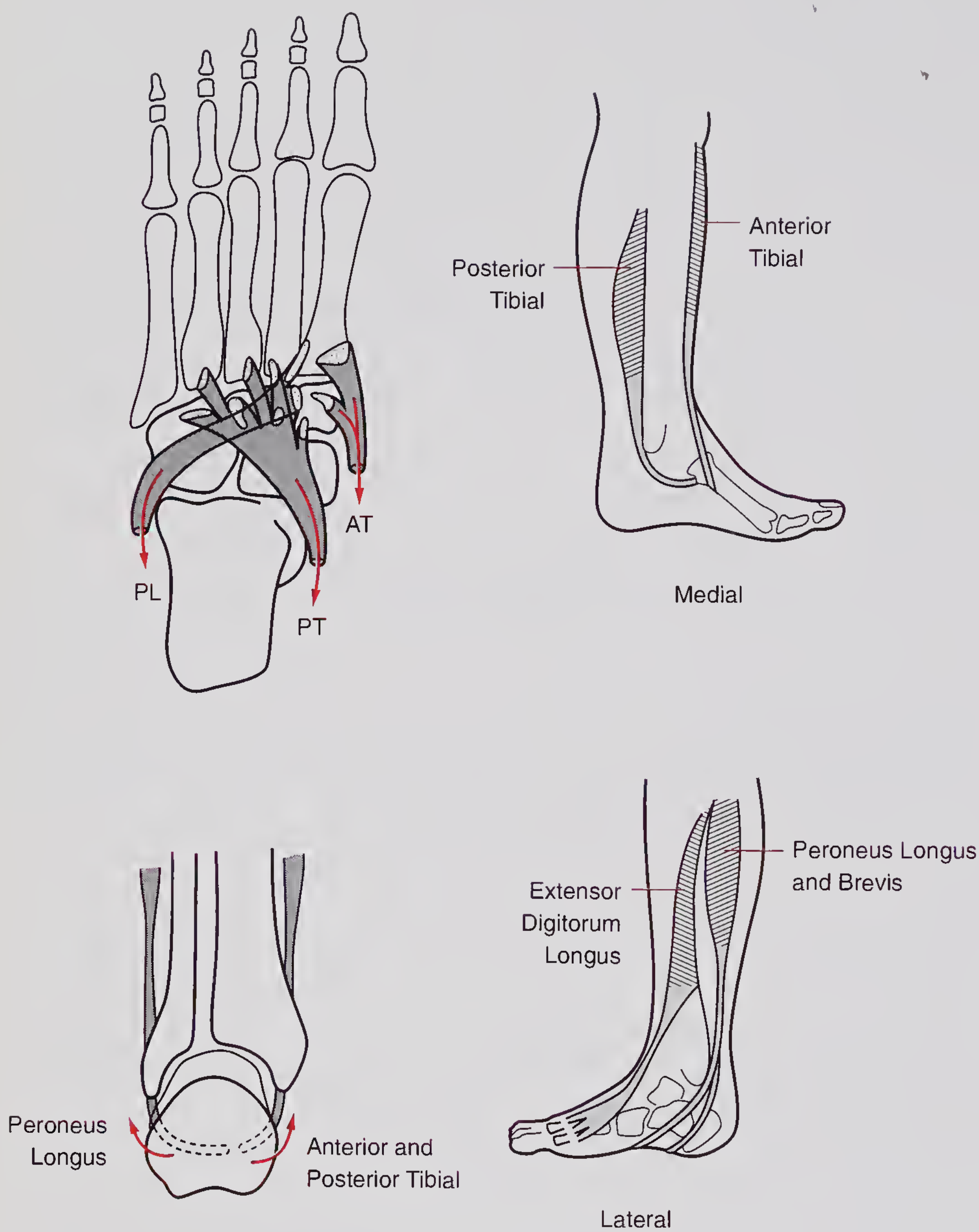


FIGURE 8.40

Extrinsic Muscles of Foot Origin, direction, and insertion of extrinsic muscles acting on foot include anterior tibial (AT), posterior tibial (PT), and peroneus longus (PL). Posterior tibialis and peroneus longus plantar flex foot, and anterior tibialis and extensor digitorum dorsiflex foot.

The extrinsic muscles acting on the foot and ankle can be divided into 3 groups: lateral, anterior, and posterior.

Lateral Group

The lateral group contains the musculi peroneus longus and peroneus brevis, which arise from the lateral aspect of the fibula with the longus arising higher on the fibula and being the most superficial. Both muscle tendons share a common sheath as they pass under and behind the lateral malleolus.

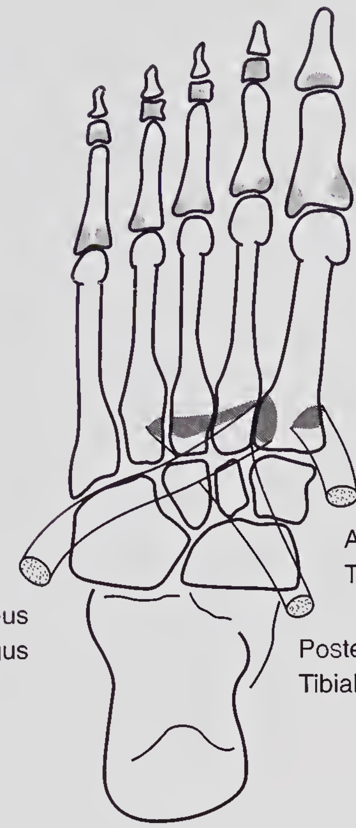


FIGURE 8.41

Tendon Attachment to First Metatarsal Bone From view of foot's plantar surface, anterior tibial tendon attaches to medial aspect of base of first metatarsal, peroneus longus attaches to lateral aspect of same bone, and posterior tibial tendon attaches to base of second, third, and fourth metatarsals.

The peroneus longus runs deeply across the plantar surface of the foot to attach to the base of the first metatarsal, and the peroneus brevis attaches to the base of the fifth metatarsal bone (Figure 8.41).

Anterior Group

The anterior group of extrinsic muscles includes the extensor digitorum longus, peroneus tertius, extensor hallucis longus, and tibialis anterior. The tibialis anterior originates from the lateral aspect of the tibia and crosses the dorsum of the foot medially to insert on the medial cuneiform bone and the base of the first metatarsal. Its action is to dorsiflex and invert the foot on the ankle.

The extensor digitorum longus arises from the entire length of the anterior surface of the fibula and the interosseous membrane between the fibula and the tibia. It inserts into the distal 2 phalanges of the lateral 4 toes. The lower fourth of this unipennate muscle is known as the *peroneus tertius*, which attaches on the dorsum of the fourth and fifth metatarsals. It is an everter of the foot.

The extensor hallucis longus arises from the middle two thirds of the anterior surface of the fibula and the interosseous membrane. It inserts on the base of the distal phalanx of the hallux.

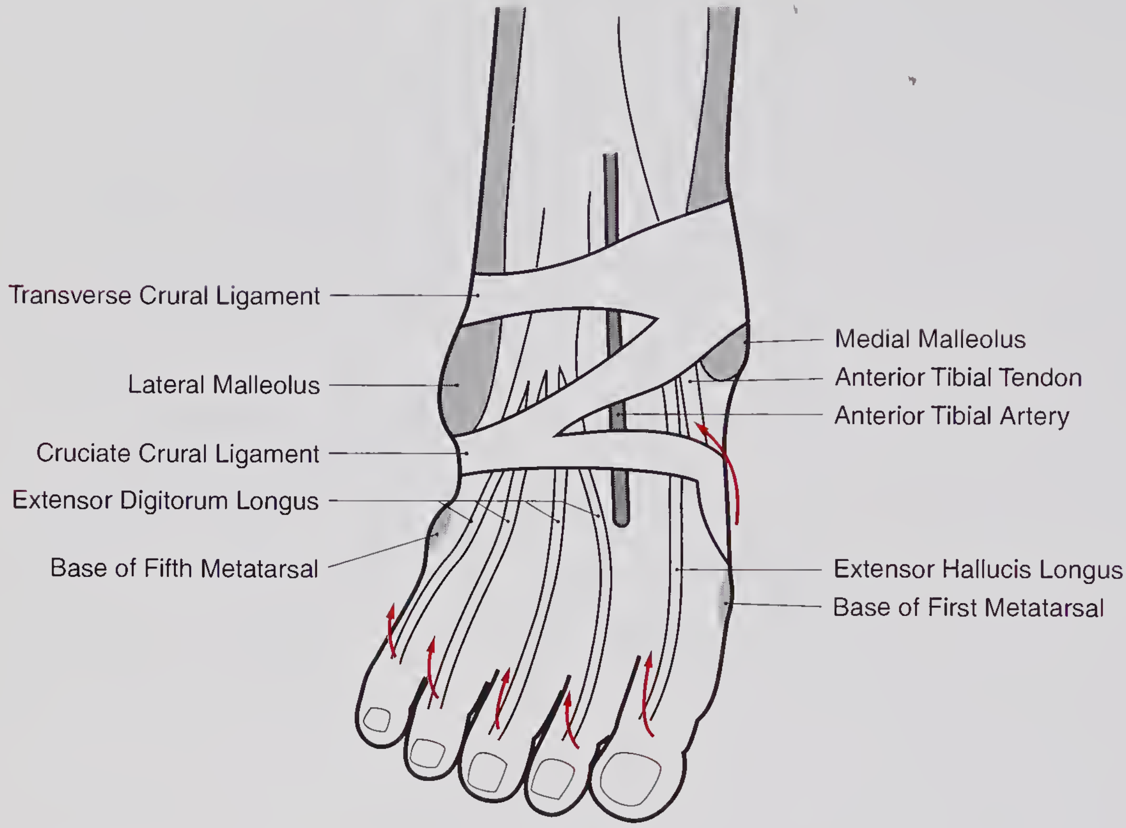


FIGURE 8.42

Dorsal View of Foot and Its Anterior Tendons All tendons on dorsum of foot. Curved arrows show their action.

The extensor digitorum brevis arises from the anterior upper surface of the calcaneus and the extensor retinaculum, which is divided into 2 segments. The superior segment extends from the medial lower aspect of the fibula and attaches to the medial aspect of the lower tibia. It covers the tibialis anterior. The lower segment forms a Y-shaped band that contains the tendons of the peroneus tertius, extensor digitorum longus, and extensor hallucis longus. It prevents bowing of these tendons when their muscles contract. The superior peroneal retinaculum attaches from the lateral distal malleolus and contains the peroneal tendons (Figures 8.42, 8.43, 8.44).

Posterior Group

The posterior group of the leg muscles are also termed the *posterior crural group* and are divided into superficial and deep. In addition to the gastrocnemius and soleus muscles, which comprise the superficial group ending in the Achilles tendon, is the plantar muscle, which lies between the gastrocnemius and soleus.

Deep Posterior Muscles

The plantar muscle has a long tendon that arises near the lateral head of the gastrocnemius muscle and inserts on the medial aspect of the Achilles tendon.

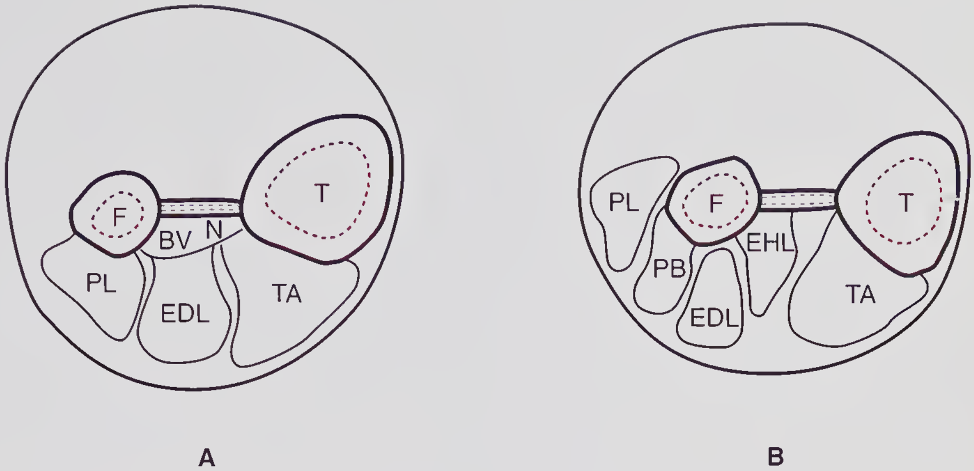


FIGURE 8.43

Sections Through Lower Leg A, Sections through lower leg to the upper third show position of anterior leg muscles: tibialis anterior (TA), extensor digitorum longus (EDL), and peroneus longus (PL). B, Lower third shows tibialis anterior (TA), extensor hallucis longus (EHL), extensor digitorum longus (EDL), peroneus brevis (PB), and peroneus longus (PL). T indicates tibia; F, fibula; BV, blood vessel; and N, nerve.

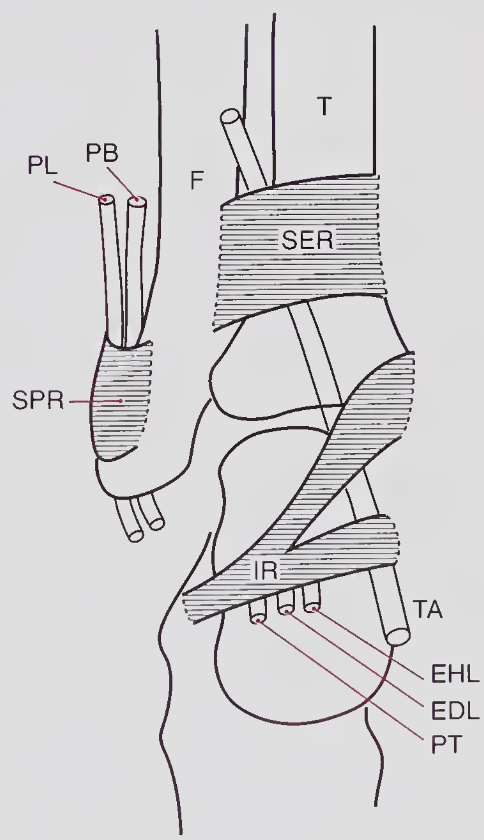


FIGURE 8.44

Extensor and Peroneal Retinaculum Retinacula that are located on dorsum of foot and ankle are divided into superior extensor retinaculum (SER); inferior retinaculum (IR), which divides into a Y form; and superior peroneal retinaculum (SPR). They contain tendons that transverse front of foot and ankle and prevent bowing: tibialis anterior (TA), peroneus longus (PL), peroneus brevis (PB), peroneus tertius (PT), extensor digitorum longus (EDL), and extensor hallucis longus (EHL). T indicates tibia; F, fibula.

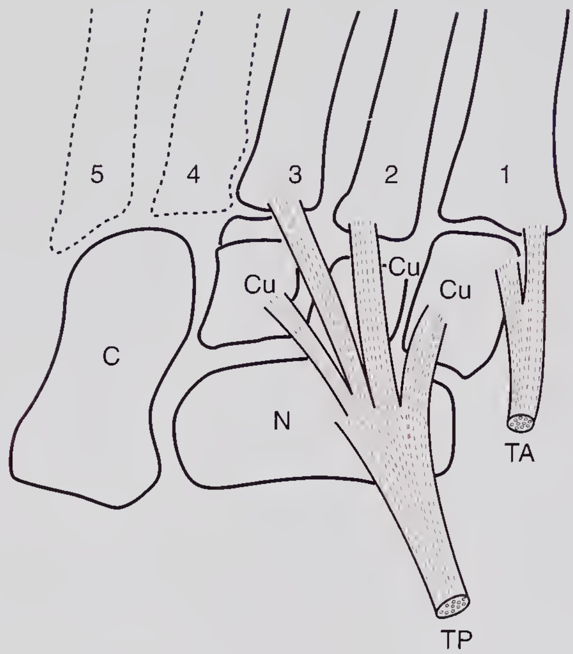


FIGURE 8.45

Tendinous Attachments of Musculus Tibialis Posterior Tibialis posterior tendon (TP) has two thirds of its tendon attaching to navicular bones (N) and slip to first cuneiform (Cu) bone and to second and third metatarsal bones. Tibial anterior tendon (TA) inserts on medial cuneiform and base of first metatarsal. C indicates calcaneus.

The tibialis posterior arises from the upper two thirds of the interosseous membrane and from the bones on each side of the membrane. It inclines medially to reach the medial malleolus and passes posteriorly to it; then it inserts onto the navicular bones and some fibers to the first cuneiform bone (Figure 8.45).

Intrinsic Foot Muscles

The intrinsic muscles of the foot originate and insert in the foot itself; mobilize the phalanges; and flex and spread the proximal phalanges. They are in 4 layers (Figures 8.46, 8.47, 8.48, 8.49).

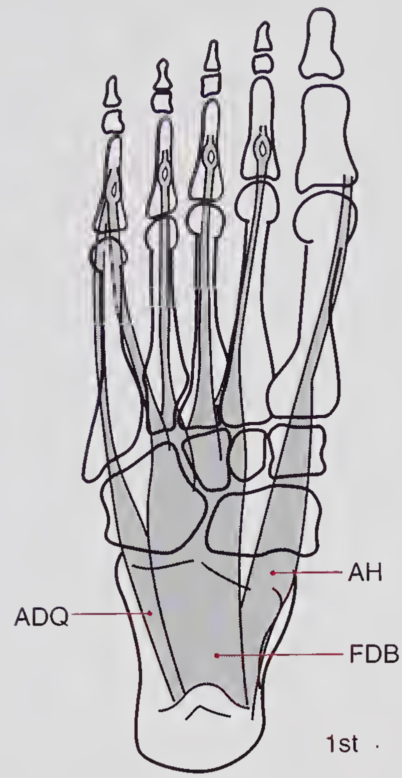


FIGURE 8.46

First Layer of Intrinsic Foot Muscles First layer of intrinsic foot muscles are abductor digiti quinti (ADQ), abductor hallucis (AH), and flexor digitorum brevis (FDB).

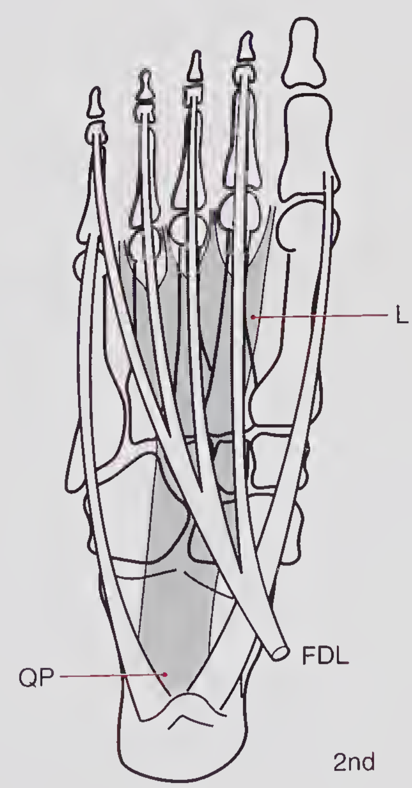


FIGURE 8.47

Second Layer of Intrinsic Muscles Second layer of muscles includes quadratus plantae (QP), lumbricales (Lu), and flexor digitorum longus (FDL).

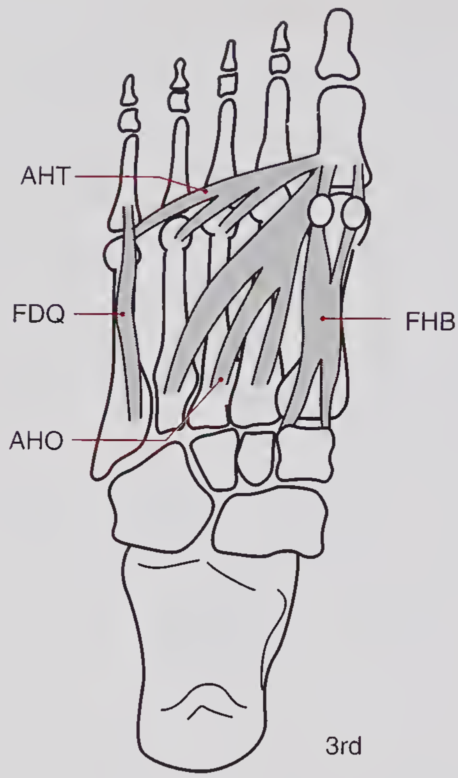


FIGURE 8.48

Third Layer of Intrinsic Foot Muscles Third layer of intrinsic foot muscles includes adductor hallucis transverse head (AHT), adductor hallucis oblique head (AHO), flexor hallucis brevis (FHB), and flexor digiti quinti brevis (FDQ).

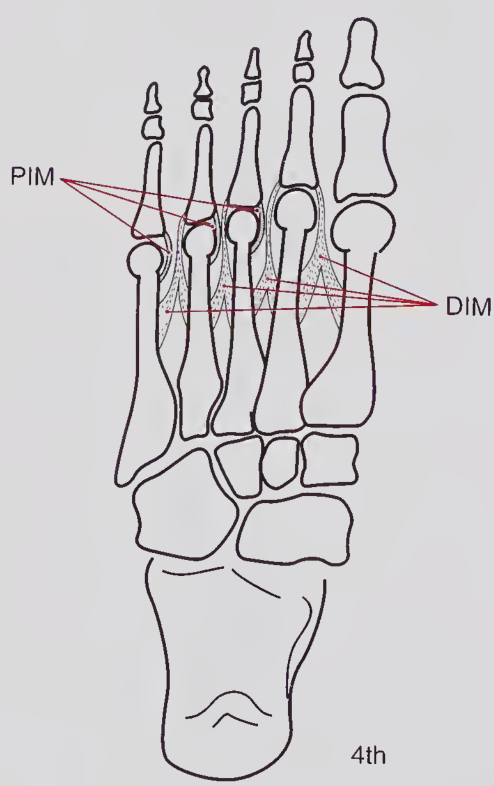


FIGURE 8.49

Fourth Layer of Intrinsic Foot Muscles Fourth and deep layer of intrinsic foot muscles includes plantar interosseous muscles (PIM) and dorsal interosseous muscles (DIM).

NERVE SUPPLY OF THE FOOT

The nerves that subserve the lower leg, foot, and toes supply the motor function and the sensory innervation that carries sensation, proprioception, and sensation of nociception. The major nerves of the lower extremity are branches of the sciatic nerve (L4, L5, S1, S2, and S3 roots) that divide into the tibial and common peroneal nerves at the popliteal level of the leg (Figure 8.50).

The tibial and common peroneal branches of the sciatic nerve also ultimately divide. The tibial nerve is essentially a continuation of the sciatic nerve, which enters the lower leg at the popliteal level between the 2 heads of the gastrocnemius muscle. It then passes deep to the soleus muscles to enter the posterior compartment of the leg. En route, the tibial nerve supplies both heads of the gastrocnemius, soleus, plantar, and posterior tibial muscles (Figure 8.51). It contributes a branch to the sural nerve, which pierces the deep fascia at the middle third of the lower leg. Then it continues downward to form the lateral calcaneal nerve, which supplies the sensation of the heel (Figure 8.52).

The posterior tibial nerve is a continuation of the tibial nerve. It starts at the level of the fibrous arch of the soleus and courses downward on the tibia to terminate into medial and lateral divisions of the plantar nerve, which supply the intrinsic muscles of the foot (Figures 8.53, 8.54).

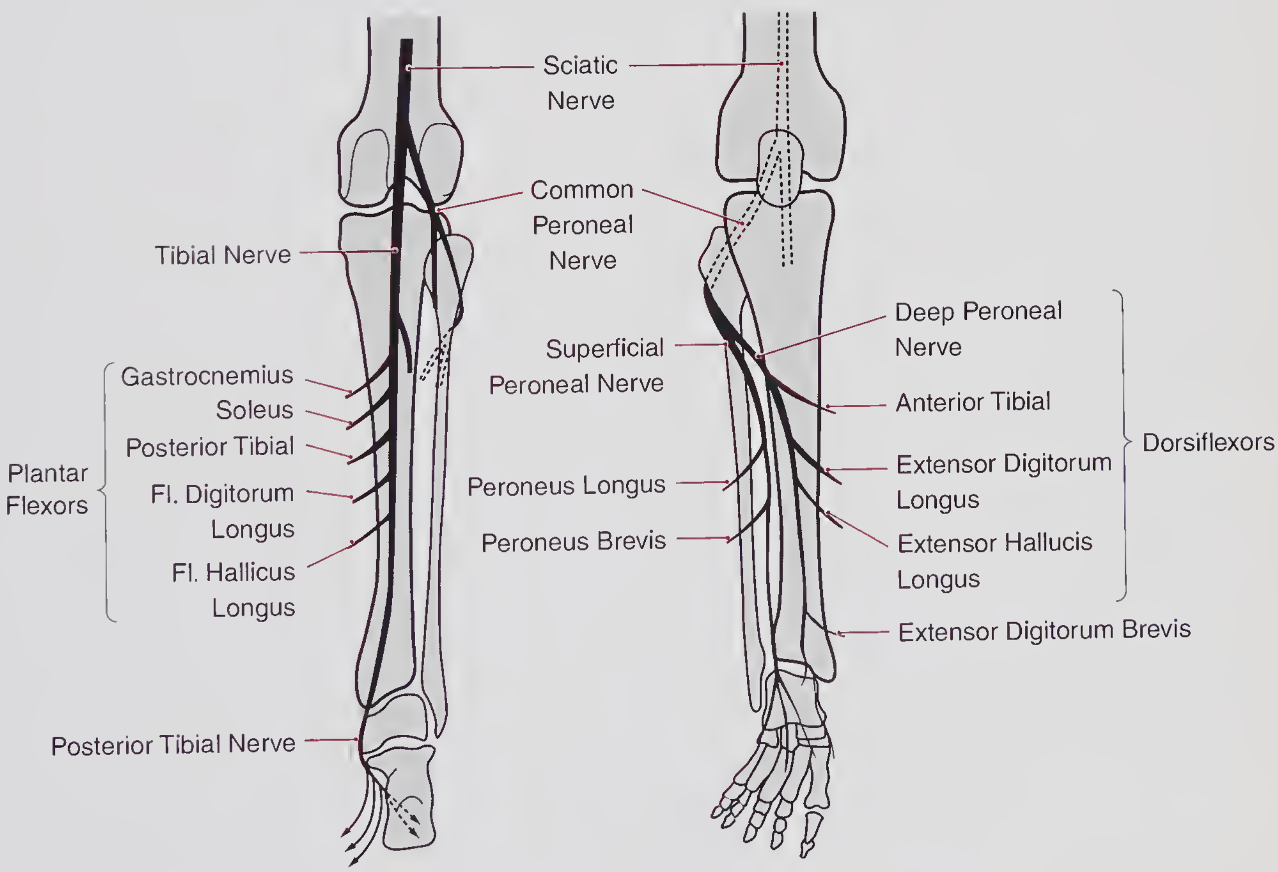


FIGURE 8.50
Innervation of Lower Leg and Foot

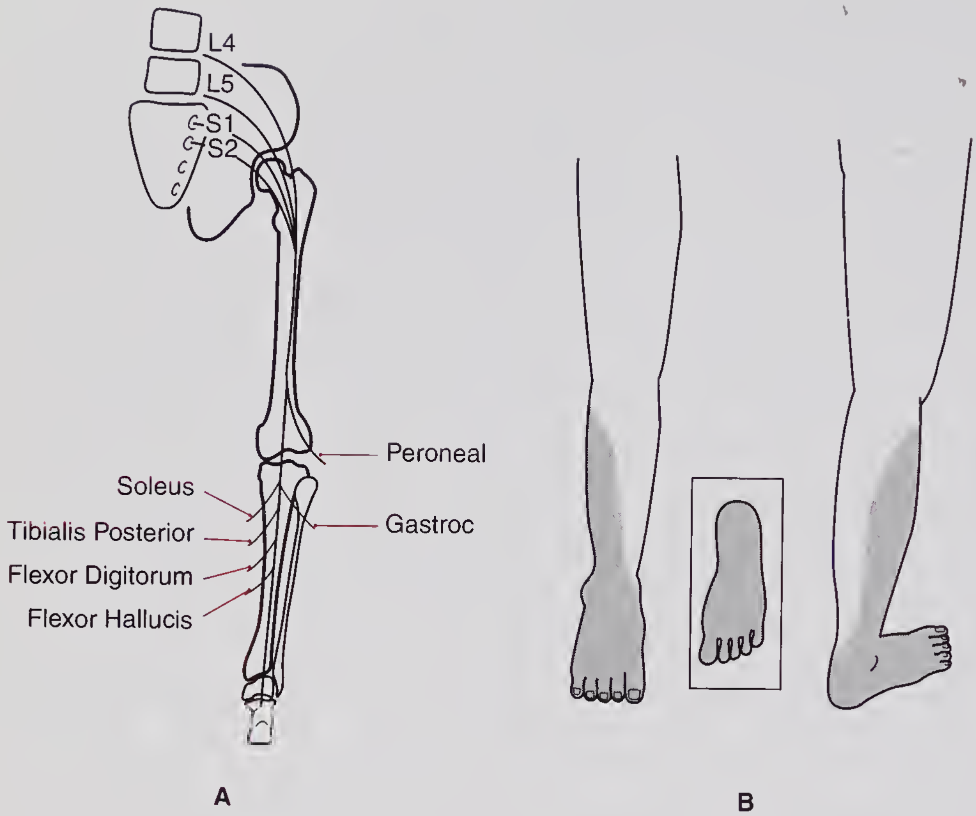


FIGURE 8.51

Motor Sensory Division of Sciatic-Tibial Nerve A, Sciatic nerve derived from roots L4, L5, S1, and S2 divides below knee to supply musculi soleus, tibialis posterior, flexor digitorum, and flexor hallucis. Gastroc indicates gastrocnemius muscle. B, Dermatomic areas supplied by tibial nerve.

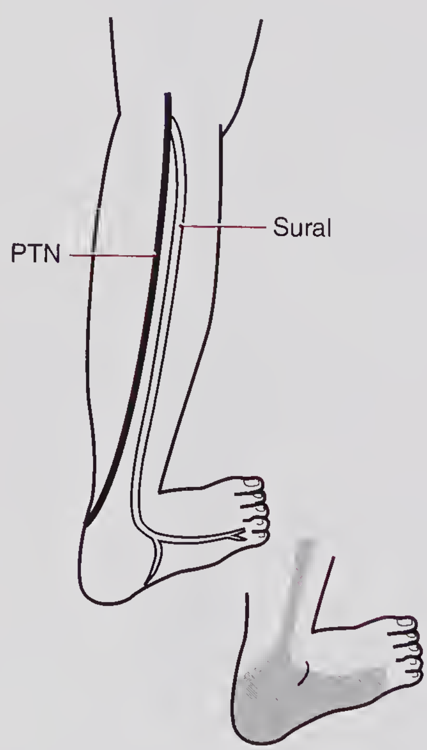


FIGURE 8.52

Sural Nerve Sural nerve carries sensation from lateral aspect of foot. It divides from posterior tibial nerve (PTN).

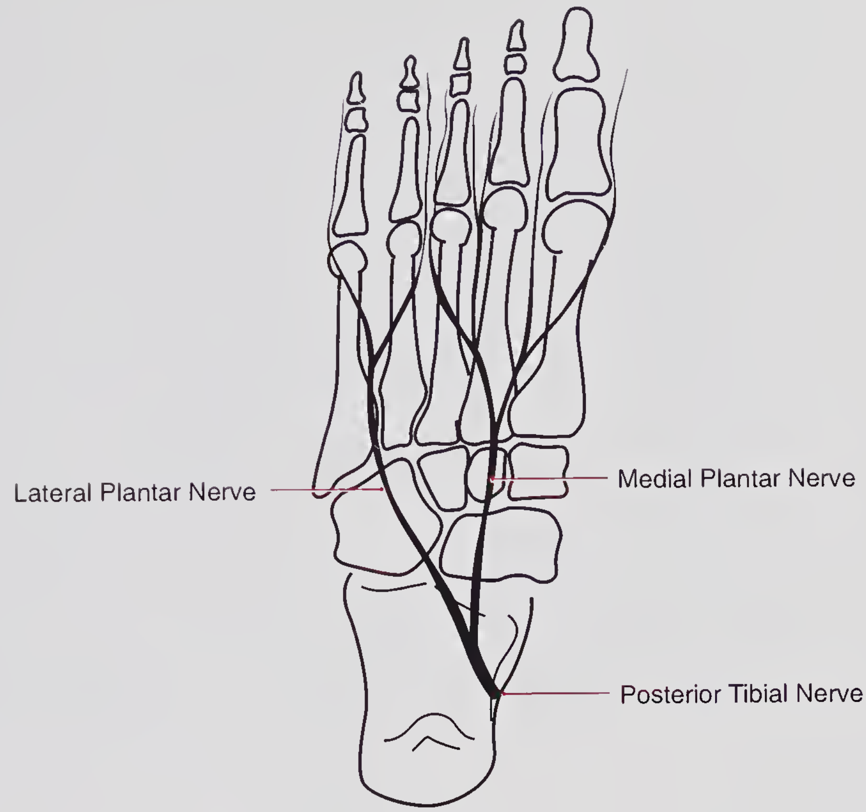


FIGURE 8.53

Plantar Nerves Posterior tibial nerve divides into lateral and medial plantar nerves.

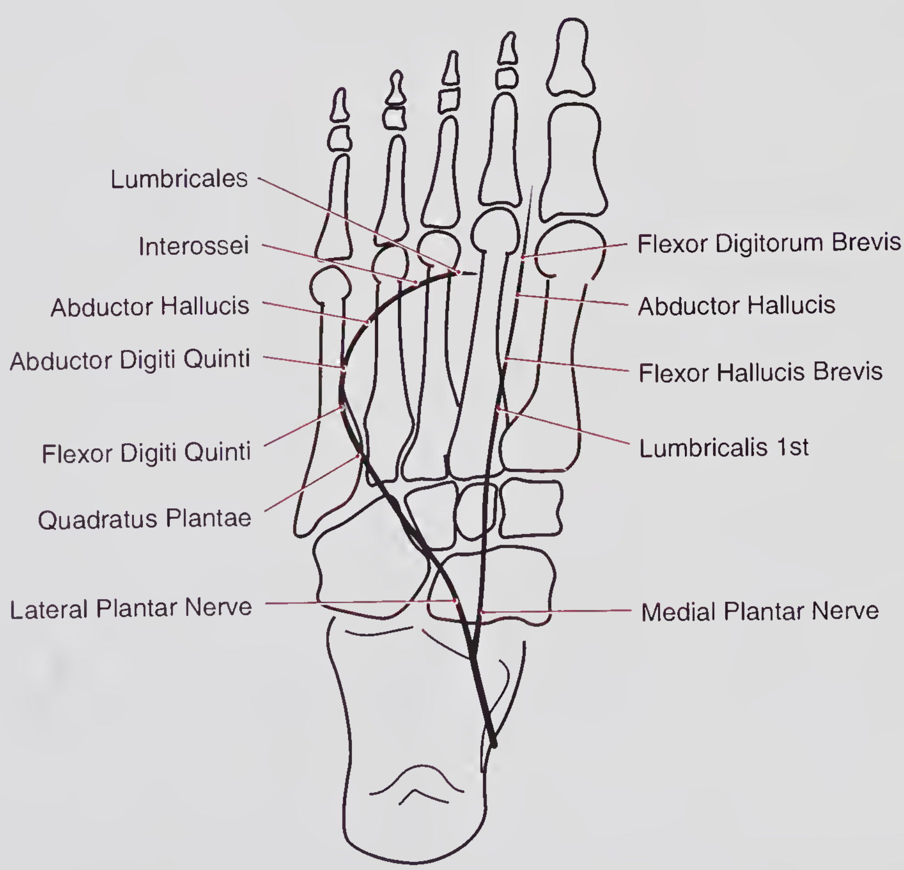


FIGURE 8.54

Muscles Innervated by Plantar Nerves Muscles innervated by plantar nerves.

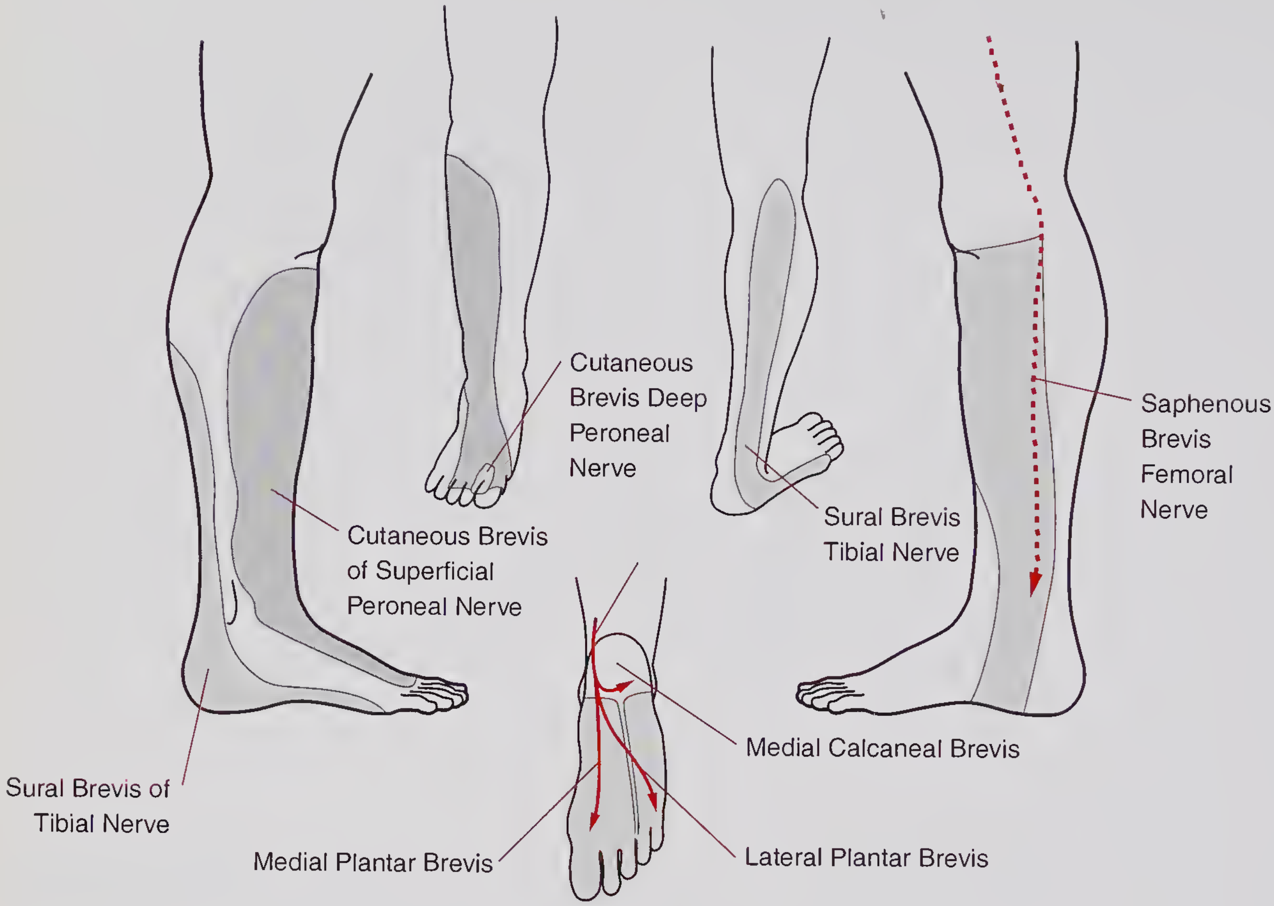


FIGURE 8.55

Dermatomic Areas Subserved by Nerves of Leg, Foot, and Toes Dermatomic areas and their nerves of leg.

The common peroneal nerve is a short nerve containing segments of L4, L5, S1, and S2 nerve roots. It courses downward along the lateral border of the popliteal fossa to reach the head of the fibula posteriorly. It winds around the neck of the fibula, where it divides into the deep and superficial peroneal nerves.

The superficial peroneal nerve descends down the leg in front of the fibula, where it pierces the fascia two thirds down and supplies the sensation of the front lateral side of the leg and the dorsum of the foot (Figure 8.55).

The deep peroneal nerve begins just below the head of the fibula. It winds around the neck of the fibula, then descends the leg in front of the interosseous membrane. When it reaches the ankle, it passes under the superior extensor retinaculum. There it divides into 2 branches, the medial and lateral, supplying the skin surface of the lateral aspect of the great and second toes. Its motor function is the extensor digitorum brevis, tibialis anterior, extensor hallucis longus, peroneus tertius, and the first dorsal interosseous.

The saphenous nerve is the termination of the femoral nerve (L2, L3, and L4 roots). After emerging from the femoral triangle, it enters Hunter's canal (subsartorial canal), where it divides into 2 branches, 1 of which accompanies the long saphenous vein down the leg (Figure 8.56).

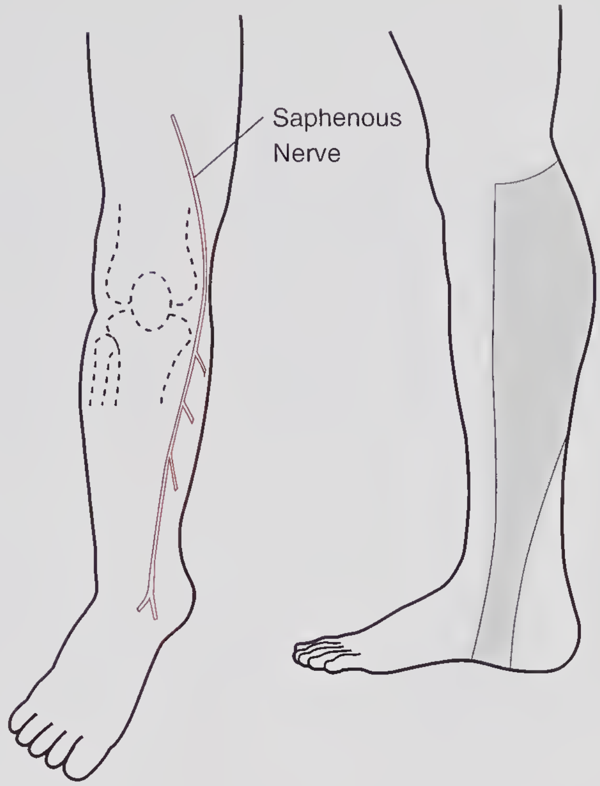


FIGURE 8.56

Saphenous Nerve Saphenous nerve is continuation of femoral nerve. It passes knee medially and primarily supplies sensation to medial leg and ankle.

BLOOD SUPPLY OF THE FOOT

The popliteal artery is a direct continuation of the femoral artery, which passes into the posterior popliteal quadrant and divides into the anterior and posterior tibial arteries going below the knee. The posterior tibial artery follows the course of the tibial nerve, supplying the posterior muscles of the leg. Upon reaching the medial malleolus, it passes to the plantar surface of the foot, dividing into the medial and lateral plantar arteries. Below the bifurcation, the popliteal artery branches with the lateral branch, passing across the interosseous membrane and then descending the lateral aspect of the leg, supplying the lateral muscles. It ends as the lateral calcaneal artery.

The other bifurcation of the popliteal artery is the anterior tibial artery, which passes anteriorly between the tibia and the fibula across the upper margin of the interosseous membrane, coursing down the anterior surface of the membrane. It supplies the muscles of the anterior chamber. Upon reaching the dorsum of the foot, it becomes the arteria dorsal artery of the foot, whose terminal branches are the dorsal metatarsal digital arteries. These distal arteries communicate with the distal branches of the plantar arteries (Figures 8.57, 8.58, 8.59).

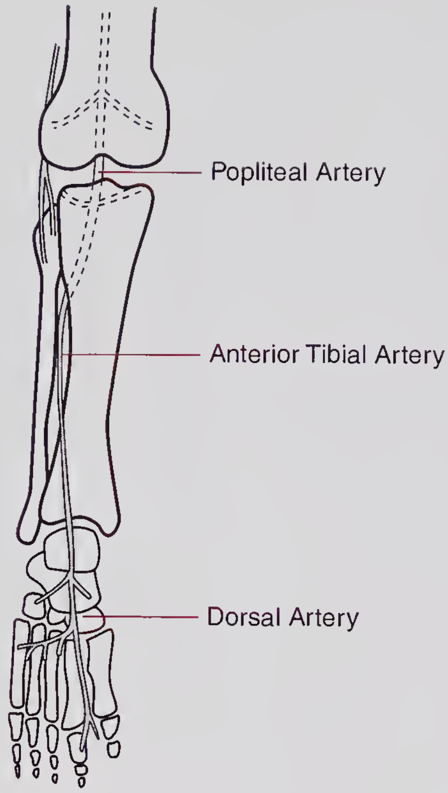


FIGURE 8.57

Arterial Supply of Leg and Foot

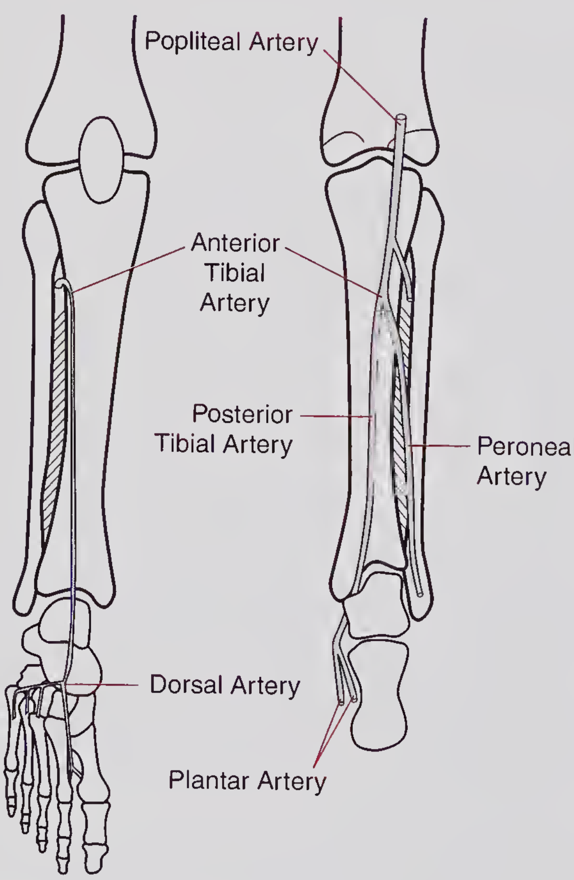


FIGURE 8.58

Anterior and Posterior Tibial Arteries

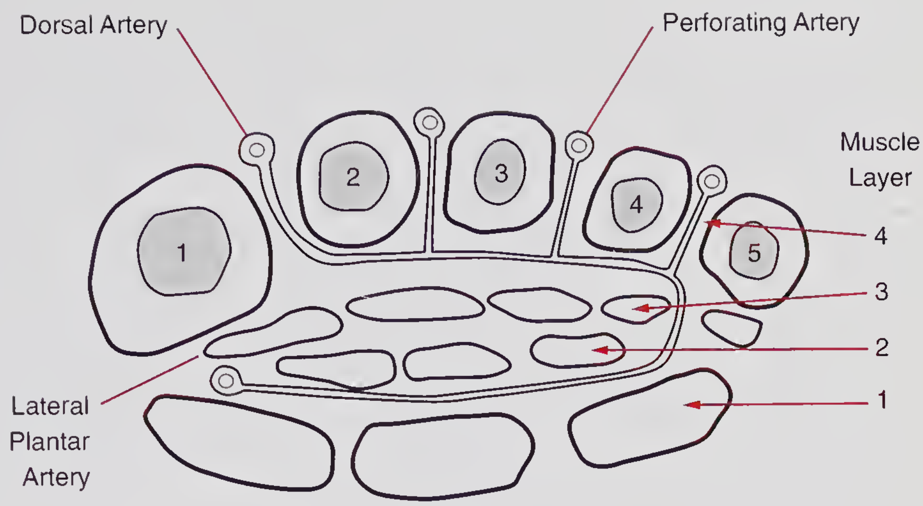


FIGURE 8.59

Blood Supply to Foot Lateral plantar artery passes medially between first (1) and second (2) layers of intrinsic muscles of sole of foot. It then moves dorsally and laterally under metatarsal bone and between fourth (4) layer of muscles. Arterial supply ends at dorsal artery of foot with intermediate perforating arteries.

THE FOOT IN NORMAL GAIT

The mechanics of motion employs many terms that need clarification before gait and the foot in gait can be meaningfully discussed.[1,2]

- **Kinematics**. The outcome measurements, including displacement, velocity and acceleration.
- **Kinetics**. The outcome measurements, including forces and movements that produce the motion.
- **Ground reaction forces**. The reaction force of all segments imposed by the ground during the stance phase. This mass acceleration consists of 3 vectors: 1 vertical and 2 shear. The vertical force can equal 1.5 to 2 times the body weight.
- **Center of pressure**. This is the center of force in the vertical vector acting on the foot during stance. It is *not* the center of gravity.
- **Joint moment**. The torque (moment) of forces—active and passive—on joints during rotation about its axis.
- **Joint reaction force**. The force of reaction between the 2 segments of a moving joint.
- **Mechanical stress**. The measurement of force per unit area.
- **Moment of inertia**. The resistance as related to the axis about which there is rotation.

Human locomotion has been compared to a wheel rolling over the ground with 2 of its spokes being the legs. The spoke that is touching the ground constitutes the *stance* phase, and the spoke that continues to move is the *swing* phase. The stance phase constitutes approximately 60% of gait, and the swing phase is 40%.

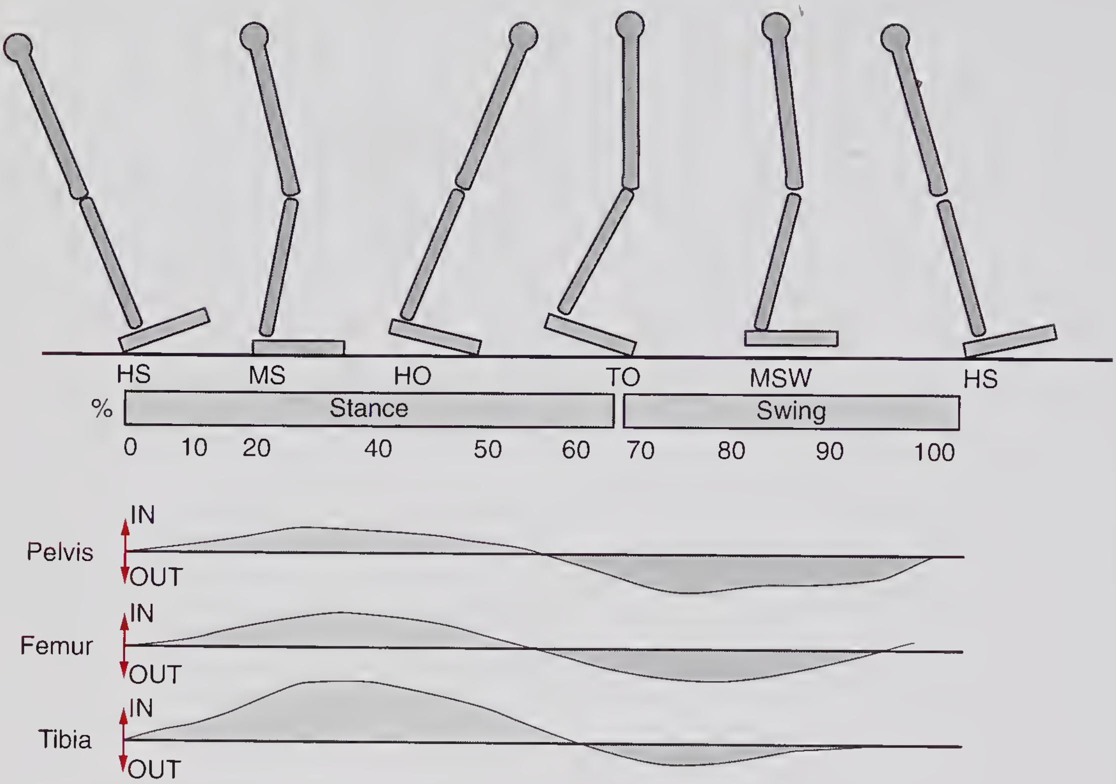


FIGURE 8.60

Gait Cycle Percentage (%) denotes increments of full gait cycle. Right leg is represented here. 0% is heel strike (HS). At 15% to 20%, knee flexes (KF); it fully extends at 30% (KE) when foot is fully pronated. At 40%, heel leaves floor (HO), and foot dorsiflexes to clear floor during swing phase (70% to 100%).

Only the foot aspect of the gait will be analyzed; the other aspects of the leg will be mentioned only when pertinent. Without the determinants, gait would be jerky, irregular, and energy consuming (Figure 8.60).

The static foot, before gait, has the weight bearing on the heel and all toes, with a predominance on the big toe (Figures 8.61, 8.62).

Foot-Ankle Relationship During Gait

During each gait cycle, the ankle travels through 4 arcs of motion. The ankle alternately dorsiflexes and plantar flexes, with the first 3 arcs occurring during the stance phase and the fourth arc occurring during the swing phase. Each arc averages between 20 to 40 degrees (Figure 8.63).

Rotational Determinants of Gait

The lower extremity undergoes rotation during gait as well as flexion and extension, all of which influence the foot and ankle. As the limb begins the swing phase, the femur slowly rotates internally, with the tibia simultaneously rotating inwardly on the femur. This internal rotation continues past the heel strike into the stance phase and ends when the foot is totally flat on the ground at midstance phase. At this point in gait, the leg begins external rotation of both the tibia and the femur, and the opposite leg begins external rotation.

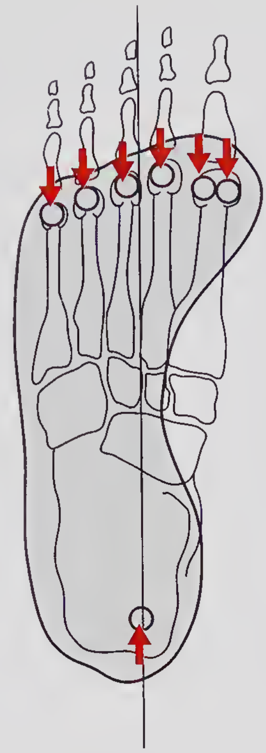


FIGURE 8.61

Sites of Weight Bearing of Static Foot During gait after heel strike, weight bearing is on foot and angles forward until weight bearing is on metatarsal head of hallux (toe 1). Then at toe off, weight bearing is on distal phalanx of big toe.

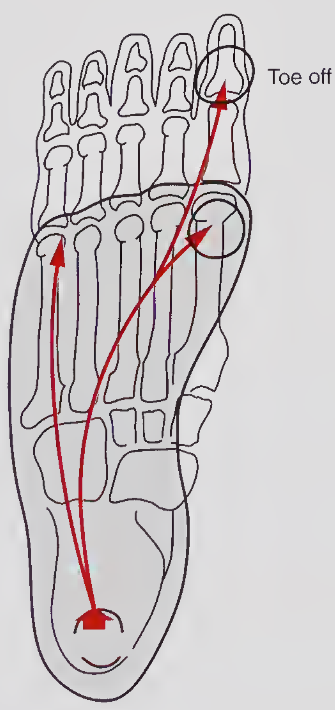


FIGURE 8.62

Weight Bearing During Normal Gait At heel strike, weight bearing is at calcaneus and, as gait progresses, weight bearing angles forward to metatarsal head of hallux, then to distal phalanx of big toe at toe off.

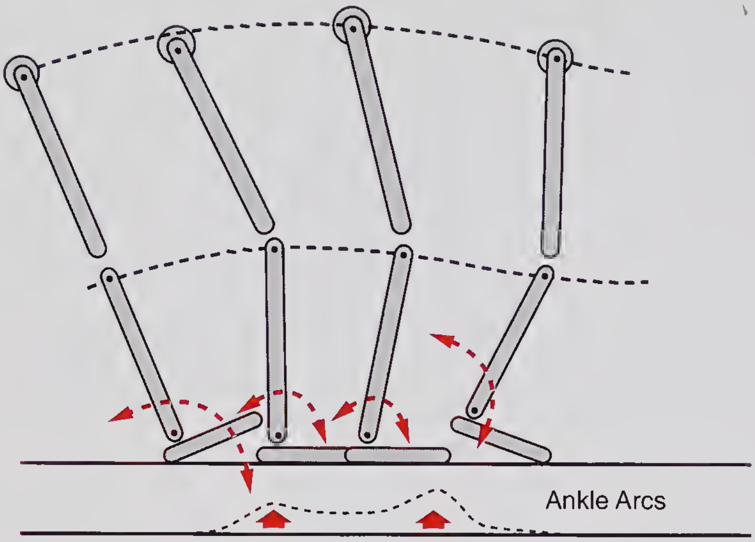


FIGURE 8.63

Ankle Arcs of Motion Timing of arcs of motion during gait. Sequence of stance, then swing phase is shown.

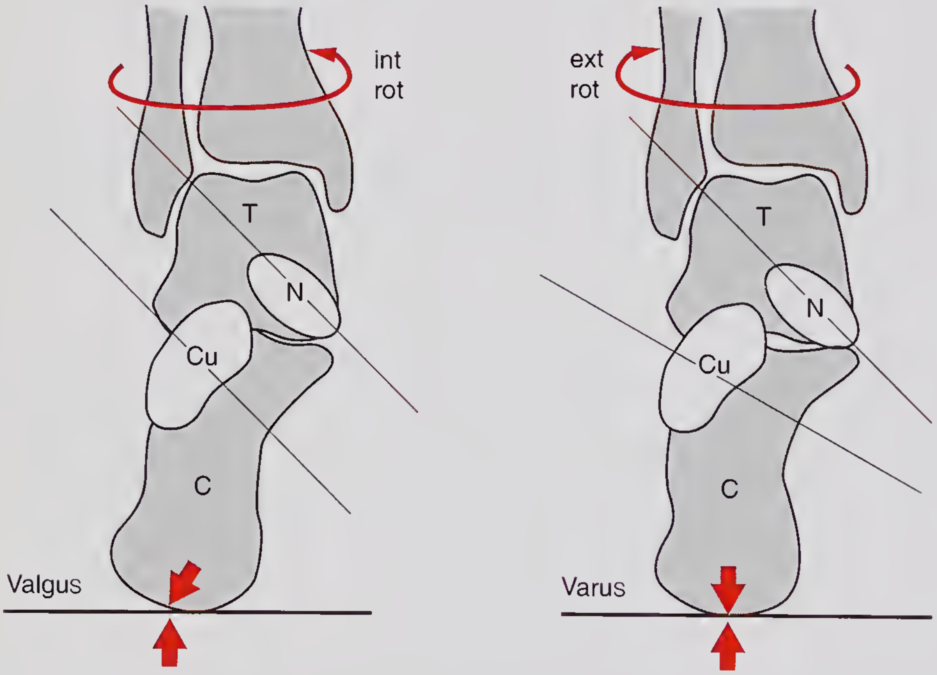


FIGURE 8.64

Subtalar Motion During Midstance Phase of Gait As leg rotates inward (int rot) and outward (out rot), talus (T) remains fixed in mortise rotation, causing valgus and varus of heel to occur at subtalar joint between cuboid (Cu), navicular (N), and calcaneus (C) bones.

Upon reaching the midstance phase with the foot flat, the foot is fixed on the ground; thus, rotation must occur at the subtalar joint, as no rotation of the talus in the mortise is allowed. With the foot now beginning the swing phase, supination and dorsiflexion of the foot begin (Figures 8.64, 8.65).

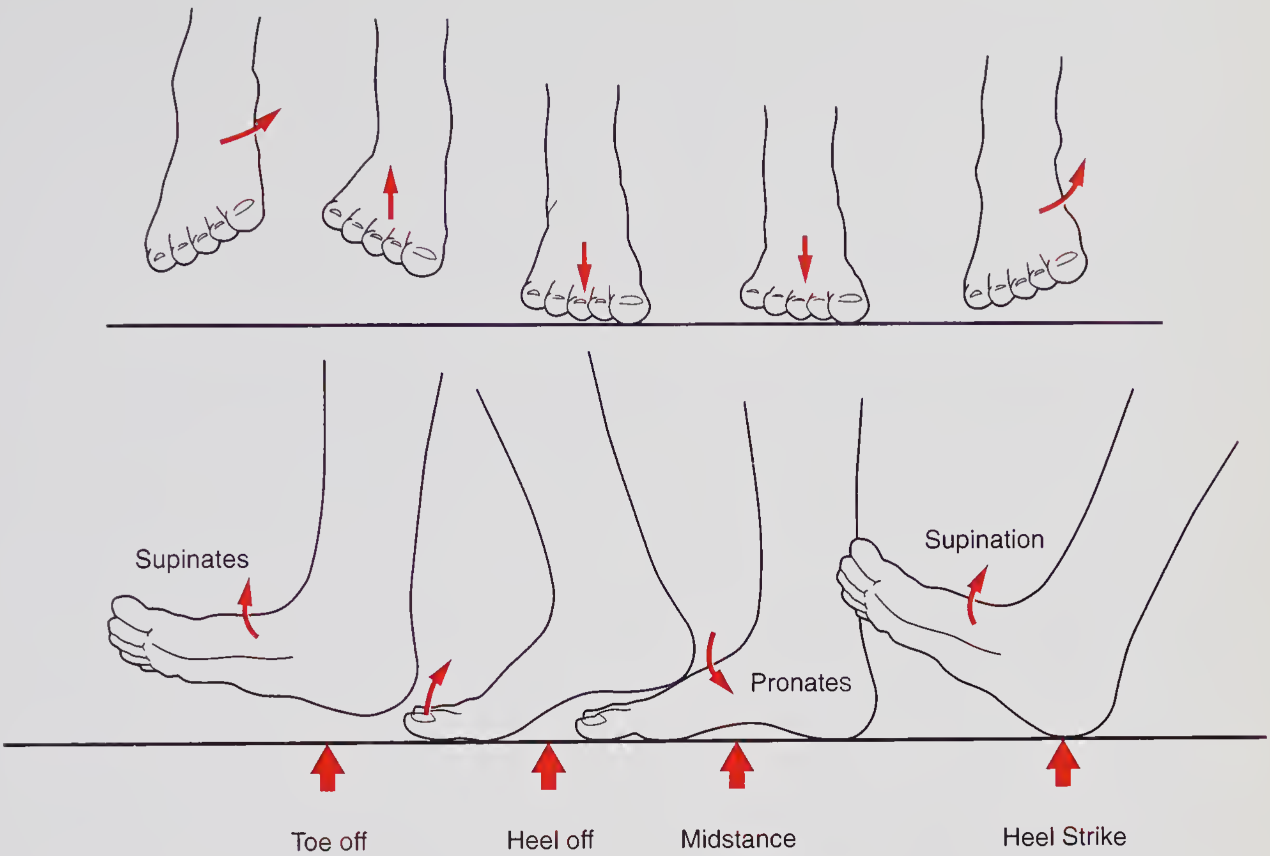


FIGURE 8.65

Supination and Pronation of Foot and Ankle During Gait At toe off, foot dorsiflexes and supinates because of muscular action of anterior tibial muscle. Supination has started at heel strike, and foot begins pronation as midstance is achieved.

Evaluation of the functional anatomy of the foot and ankle during clinical practice ascertains where, when, and why pathology has occurred and impairment has begun.

REFERENCES

1. Saunders JB, Inman VT, Eberhart HD. The major determinants in normal and pathological gait. *J Bone Joint Surg*. 1953;35A:543.
2. Perry J. *Gait Analysis: Normal and Pathological Function*. New York, NY: McGraw-Hill; 1992.

INDEX

G

J

K

L

M

P

Q

T

The Illustrated Guide to Functional Anatomy of the Musculoskeletal System, a new text from the American Medical Association, is designed to familiarize you quickly with musculoskeletal function and will help you

- understand and evaluate normal functional anatomy;
- ascertain how deviation from normal functic
- quickly determine how the body works throu number of illustrations (nearly twice the nur than similar resources).

The text also uses colored line drawings to tho with clear, concise text from an expert educator thorough coverage of the entire body with releva and neck, thorax, abdomen, and pelvis.

Logically integrating regional and systemic cove new resource offers a complete overview of the su were developed with you in mind to quickly elici studies and appropriate therapeutic approaches. T independent study as well as for use in conjuncti

For more information on AMA products, call 80 www.amapress.com.

AMA press

OP857003
BQ75:03-P-076:8/03

ISBN 1-57947-408-X
90000
9 781579 474089